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BULLETIN
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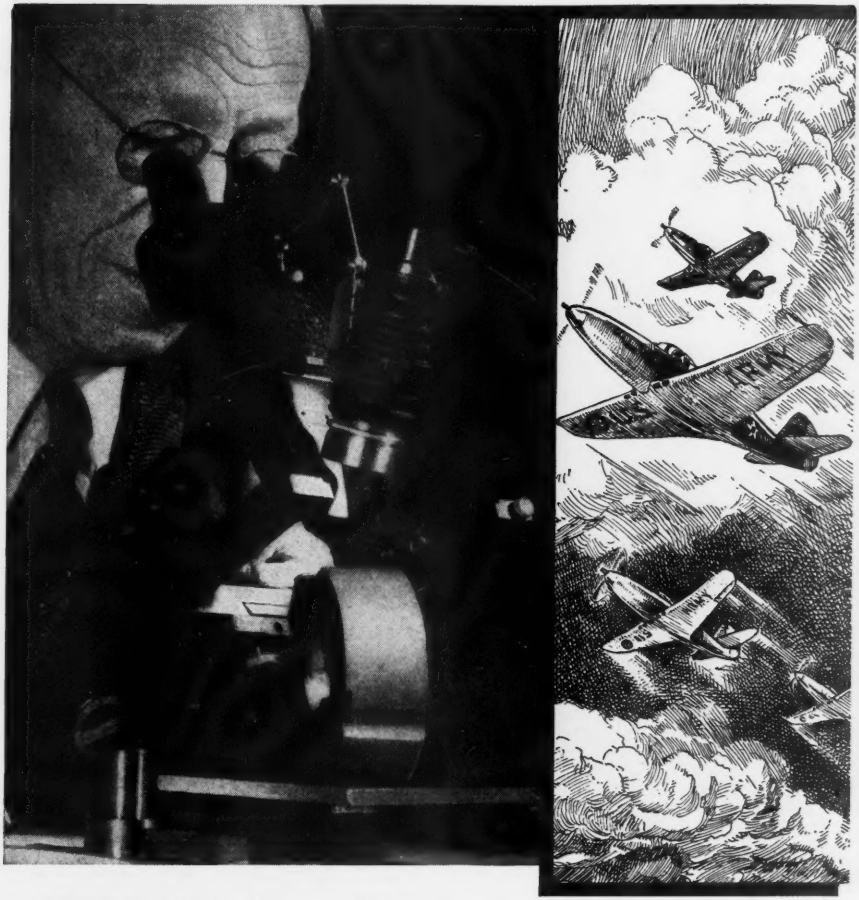

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APRIL, 1945

LOWER ORDOVICIAN AND UPPER CAMBRIAN SUBSURFACE SUBDIVISIONS IN NORTH-CENTRAL TEXAS[1]

A. J. CROWLEY[2] AND LEO HENDRICKS[3]
Washington, D.C., and Austin, Texas

ABSTRACT

An investigation of the subsurface Lower Ordovician and Upper Cambrian limestones and dolomites of north-central Texas was made mainly by a microscopic examination of well cuttings and siliceous residues derived from the cuttings, during the fall of 1943 and the spring of 1944. These rocks are generally known as the Ellenburger limestone. They were subdivided into six units of which two were further subdivided into two sub-units each. Each unit and sub-unit contains siliceous residues that characterize it and that persist throughout the region. Eight cross sections show the correlations of these subdivisions from well to well. Unit A, the youngest of the subdivisions, is present only in the eastern and northeastern parts of the region where it has been preserved in a regional syncline. The distribution of the other units is erratic because at least one period of erosion during, and several such periods following, the deposition of these beds have removed unequal parts of them throughout the region.

INTRODUCTION

The area described in this report comprises a roughly triangular area in Texas extending from the margin of the Central Mineral region in McCulloch, San Saba, and Lampasas counties on the south to the Red River on the north, and from northern Childress County on the northwest to eastern Cooke County on the northeast. The project included a detailed stratigraphic investigation of the Lower Ordovician and Upper Cambrian limestones and dolomites, including beds generally known as the Ellenburger limestone. The investigation was conducted mainly by a microscopic examination of cuttings obtained from deep wells and of insoluble residues prepared from the cuttings.

[1] This paper has been prepared in coöperation between the United States Geological Survey and the Bureau of Economic Geology of the University of Texas, and is released to the American Association of Petroleum Geologists for publication in the *Bulletin*. Manuscript received, January 9, 1945.

[2] United States Department of the Interior, Geological Survey.

[3] University of Texas Bureau of Economic Geology.

The objectives of the investigation were: (1) to subdivide the Lower Ordovician and Upper Cambrian limestones and dolomites into units that can be recognized in the subsurface from well to well and to correlate these subdivisions with the exposed beds in the Central Mineral region; (2) to identify the subdivisions that are oil-bearing and others that are barren of oil or gas in oil wells and dry holes; and (3) to determine the physical properties of beds that make them suitable as oil and gas reservoirs. The first objective has been partly accomplished and the results are given in this progress report. The phases of the investigation relating to the second and third objectives will be continued and the results will be published later, though a few observations about the third objective are included here.

FIELD WORK

The investigation was undertaken as a coöperative project of the University of Texas Bureau of Economic Geology and the Geological Survey of the United States Department of the Interior. The project is actually an expansion of an earlier investigation of the Ellenburger group conducted several years ago by Hendricks.[4] The work on the project was carried on between November, 1943, and May, 1944, at Fort Worth and Austin, Texas. The siliceous residues were prepared at Austin by William J. Bruce, under the direction of Leo Hendricks. The drafting of the plates for the report was done in part by George E. Vaughan, Jr., and in part by the senior writer. An investigation of the Cambrian and Ordovician beds exposed in the Central Mineral region of Texas was conducted by P. E. Cloud of the United States Geological Survey and V. E. Barnes of the University of Texas Bureau of Economic Geology, simultaneously with the subsurface investigation made in north-central Texas by the writers. Several conferences were held with Cloud and Barnes in the field in the Central Mineral region during the course of the investigation and the two projects—subsurface and surface—were coördinated as far as possible.

ACKNOWLEDGMENTS

The writers are deeply grateful to the department of geology of Texas Christian University at Fort Worth for providing office and laboratory space for the senior writer. Several oil companies at Fort Worth, particularly the Gulf Oil Corporation, and others at Wichita Falls, particularly the Shell Oil Company, supplied well samples for making siliceous residues and other data that greatly aided the investigation. The writers are indebted to P. E. Cloud of the United States Geological Survey and V. E. Barnes of the University of Texas, Bureau of Economic Geology for much information on the Cambrian and Ordovician rocks in the Central Mineral region; these data included detailed measured strati-

[4] Leo Hendricks, "Subsurface Divisions of the Ellenburger in North-Central Texas," *Univ. Texas Bur. Econ. Geol. Bull. 3945*, December 1, 1939 (1940), pp. 923–68.

graphic sections, paleontologic determinations, and oral discussions during conferences in the field.

PREPARATION OF SILICEOUS RESIDUES

The laboratory method for preparing siliceous residues, devised by McQueen,[5] was followed largely in this investigation. Samples of well cuttings varying from 3 to 10 grams, according on the quantity available, were immersed in 12 per cent hydrochloric acid at room temperature until all carbonate had been dissolved. For a few samples it was necessary to warm the acid to slightly above room temperature. Following this, the residues of the samples were carefully washed with tap water, dried, and stored in glass vials, properly labelled as to well, location, and depth, and examined with the aid of a microscope. These residues, commonly referred to as "siliceous residues," are available to the public in a permanent file in the University of Texas Bureau of Economic Geology at Austin.

DEFINITION OF TERMS

The following are definitions of terms used in the descriptions of the siliceous residues.

Finely granular silica refers to finely clustered aggregates or individual particles of very fine sand, chert, and silt, commonly in clusters containing varying amounts of clay or shaly material.

Smooth-textured chert refers to chert that has a conchoidal fracture with a smooth vitreous surface, exhibiting little or no pebbled effect on the surfaces of the fractures. This type of chert fractures much like glass, though the chert does not resemble glass in any other way.

Granular-textured chert refers to chert whose fracture surface exhibits a pebbled or granular to sub-granular grain resembling certain varieties of chalcedony or very fine-grained quartzite; it may be granulated.

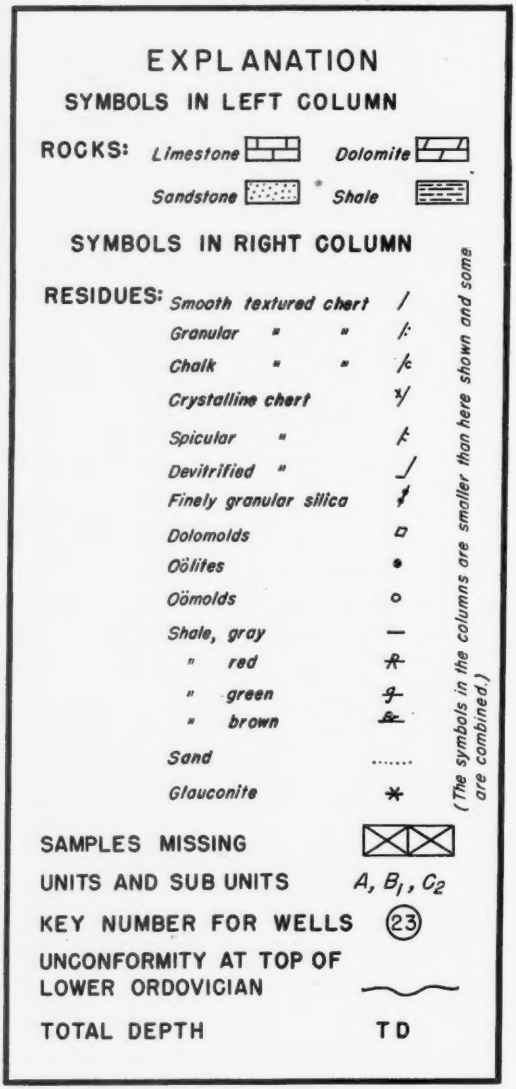
"Crystalline" chert refers to chert having a drusy surface. The term also refers to clear secondary quartz.

Devitrified chert refers to chert that has the appearance of having been exposed to the weather for a long time.

Chalk-textured chert refers to siliceous residues that resemble chalk or tripolite. Most of it is almost pure white, soft and easily broken by the pressure of a fingernail.

Spicular chert generally refers to chert that has a faint, irregular pattern caused by included clusters of spicules and rarely by individual needle-like spicules. The appearance of these clusters of spicules is distinctly different from spicular cherts in both younger and older rocks elsewhere in the Mid-Continent. Crushed, silicified specimens of the sponge *Archeoscyphia* exemplify this structure.

[5] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. and Mines 56th Bien. Rept.* (1931), Appendix 1, pp. 5–8.



Explanation of symbols used in Plates 2–10.

Dolomoldic chert refers to chert that appears to have been formed around and between individual dolomite rhombs. After the dolomite is dissolved the impressions or molds of the rhombs remain. This term corresponds with the term "dolocastic chert" of McQueen.[6]

Oölitic chert refers to chert containing siliceous oölites either embedded or free.

Oömoldic chert refers to chert that appears to have been formed around oölites. After the oölites are dissolved the matrix containing the molds of the oölites remains. This term corresponds with the terms "oölicastic" and "oöcastic" of Hendricks[7] and Cole,[8] respectively.

Shale refers mainly to green and some gray, brown, or red waxy shale, in some places slightly silty and dolomoldic. The shale probably occurs as cavity filling, in styolites, or as thin flakes along bedding planes.

Sand refers to single grains or aggregates of fine to medium, mainly rounded to sub-rounded, commonly frosted or pitted quartz grains, a few of which show secondary growth. Possibly some grains of feldspar have been included with the sand.

Dolomite, as the term is used here, refers to calcareous rocks that have a retarded effervescence in cold dilute hydrochloric acid.

SUBSURFACE STRATIGRAPHY

The greater part of north-central Texas is underlain at depths ranging from about 1,000 to 11,000 feet by a sequence of dolomites and limestones of Lower Ordovician and Upper Cambrian age. The presence of these rocks in the region has been revealed by the drilling of many deep wells for oil and gas. The total thickness of the sequence varies widely from place to place; its maximum thickness, as estimated by compiling data from many wells, each of which penetrated only a part of the total, is somewhat greater than 4,500 feet. An almost complete section, as revealed by several key wells, is shown on Plate 2. No single well has penetrated the entire sequence.

The Upper Cambrian and Lower Ordovician rocks are exposed in the Central Mineral region on the south and are equivalent to parts of the subsurface sequence of north-central Texas. Preliminary correlations between the subsurface subdivisions established by the writers and detailed stratigraphic sections measured by Cloud and Barnes indicate that a thicker sequence is present in north-central Texas than in the Central Mineral region; not only are the individual units thicker but some of the uppermost beds that are present in the subsurface appear to be absent in the Central Mineral region. The thickness of units C, D,

[6] H. S. McQueen, *op. cit.*, p. 9.

[7] Leo Hendricks, "Subsurface Divisions of the Ellenburger in North-Central Texas," *Univ. Texas Bur. Econ. Geol. Bull. 3945* (1940), p. 961.

[8] Taylor Cole, "Subsurface Study of Ellenburger Formation in West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 8 (1942), p. 1400.

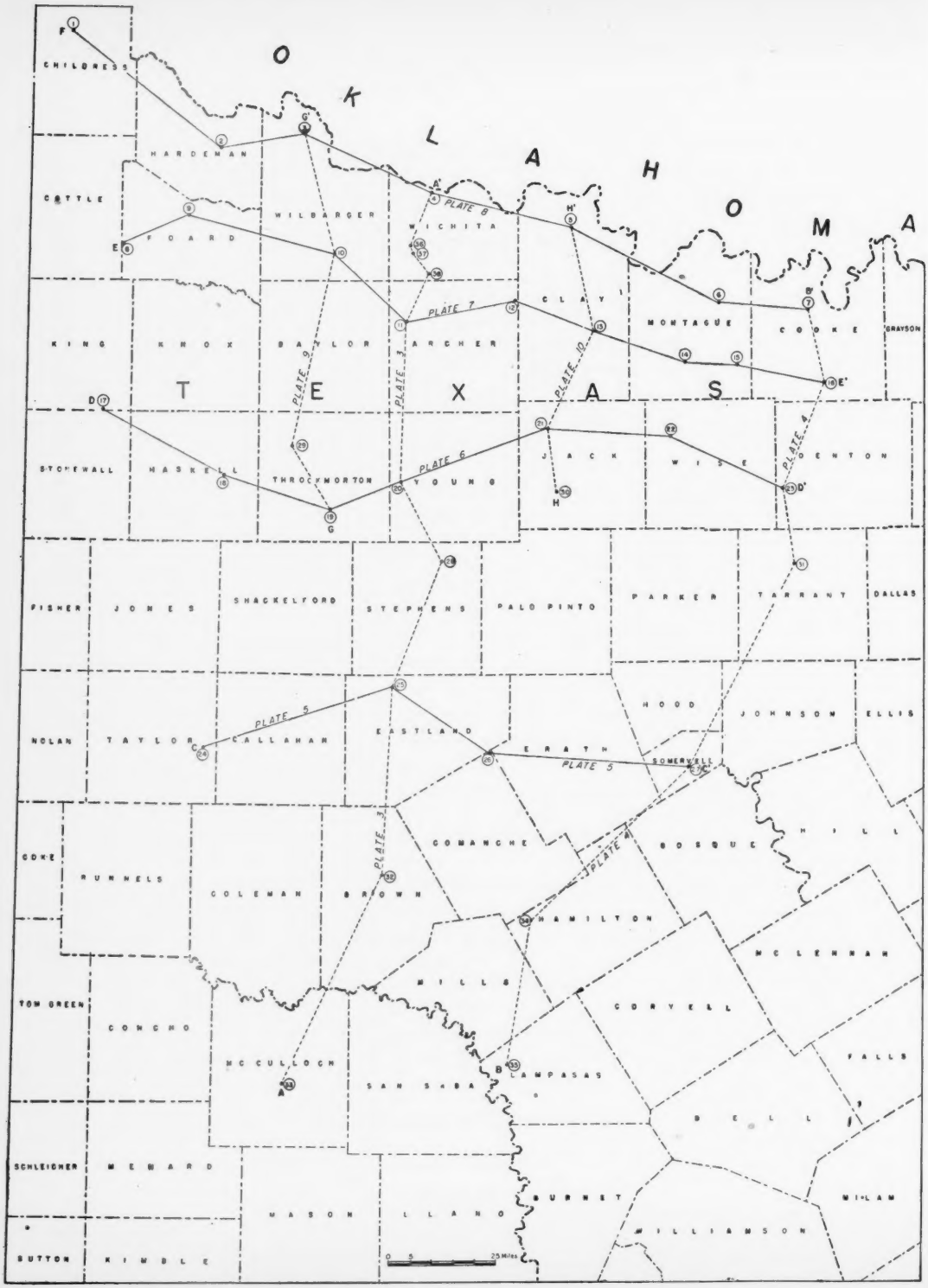


PLATE 1.—Key map of north-central Texas showing location of wells and lines of cross sections shown in Plates 2–10.

LIST OF WELLS LOCATED BY INDEX NUMBERS IN PLATES 1–10

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
1	Childress	Humble Oil & Rfg. Co.	1	Smith	H. & G.N.R.R.	Block 9, Sec. 27, 1,320 ft. from south and east lines
2	Hardeman	Amerada Petroleum Corp.	1	W. M. Rice *et al.*	H.W. & N.W.R.R.	Sec. 81, 1,679 ft. from north line and 1,637 ft. from west line
3	Wilbarger	Amerada Petroleum Corp.	1	Goodpasture	H. & T.C.R.R.	Block 15, Sec. 35, center of SW. ¼, SW. ¼
4	Wichita	Deep Oil Development Co.	1	Hirschi	D. Cowan	10 miles from west line of county, 1 mile south of Red River
5	Clay	The Texas Co.	41	Byerts	Gaston	Byerts Subdivision, Block 19
6	Montague	Sinclair Prairie Oil Co.	2	Doty	J. H. Jones	426 ft. from east line and 494 ft. from south line of survey
7	Cooke	Humble Oil & Rfg. Co.	1	Rivoire	M. Charo	330 ft. from north and west lines of survey
8	Foard	The Texas Co.	3	Johnson	S.P.R.R.	Sec. 36
9	Foard	The Texas Co.	1	Margaret Unit	H. & T.C.R.R.	Block 4, Sec. 431, 990 ft. from north line and 330 ft. from west line
10	Wilbarger	Wilcox Oil Co.	1MM	Waggoner	H. & T.C.R.R.	Block 17, Sec. 8, center NE. ¼, NE. ¼
11	Archer	Phillips Petroleum Co.	1	Pendry	H. & T.C.R.R.	Block 4, Sec. 13, 660 ft. from south and west lines of 160-acre tract
12	Archer	Bass & Dillard	1	McGregor	E. Goodwin	467 ft. from north and west lines of 144-acre tract
13	Clay	Shell Oil Co.	1	Coleman	Calhoun County School	Lot 24, 252 ft. from north line and 467 ft. from east line
14	Montague	Continental Oil Co.	1	Mueller	F. Hamilton	467 ft. from southeast and southwest lines of NE. 166-acre tract
15	Montague	Sinclair Prairie Oil Co.	1	Jones	I. Singletary	1,400 ft. from west line and 467 ft. from north line
16	Cooke	Benson Oil Co.	1	Daugherty	B. Garner	10 miles south and 4 miles west of Gainesville
17	King	Mid-Continent Petroleum Corp.	1	Burnette	H. & T.C.R.R.	Block F, Sec. 16, 1,320 ft. from south line and 660 ft. from east line
18	Haskell	Amerada Petroleum Corp.	1	Kleiner	J. M. Cass	660 ft. from north and east lines
19	Throck-morton	Humble Oil & Rfg. Co.	1	Durham	T.E. & L.R.R.	Sec. 1,627; 933 ft. from north and west lines
20	Young	Standard Oil Co. of Texas	1	Hulbert	T.E. & L.R.R.	Sec. 726; 1,207 ft. from south line and 660 ft. from east line of E. ½
21	Jack	Standard Oil Co. of Texas	1	Carter	Wm. MacDonald	Block 5, 495 ft. from north and east lines
22	Wise	Hunt Oil Co.	1	Stack	Adam Johnson	385 ft. from south line and 554 ft. from east line
23	Denton	A. G. Carter *et al.*	1	Allen	S. Westbrook	440 ft. from north and west lines of 640-acre tract
24	Taylor	J. B. Jameson	1	Webb	Lunatic Asylum	Sec. 46, center NE. ¼, NE. ¼
25	Eastland	J. H. Hopkins	1	Davis	H. & T.C.R.R.	Block 4, Sec. 54; 1,005 ft. north and 330 ft. west of SE. corner of N. ½
26	Comanche	Gallagher & Lawson	1	Terry	N. H. Kuykendall	840 ft. from north line and 429 ft. from east line of 53-acre tract
27	Somervell	M. E. Davis *et al.*	1	Cousins	John Echols	East corner of 50-acre tract
28	Stephens	Shell Oil Co.	1	Allen	S.P.R.R.	Block 2, Sec. 14; 495 ft. from south line and 495 ft. from east line
29	Throck-morton	Swenson Oil & Gas Co.	1	Swenson	B.B. & C.R.R.	Sec. 173; 2,000 ft. from south line and 4 ft. from east line
30	Jack	Continental Oil Co.	1	Robertson	M. J. Swan	1,050 ft. from south line and 990 ft. from west line
31	Tarrant	Sullivan Oil Co.	1	Putnam	Milly Gilbert	1,434 ft. from north line and 1,540 ft. from west line of 200-acre tract
32	Brown	Bartles & Dumenil	1	Baugh	O. Dalton	Sec. 26
33	McCulloch	City of Brady	3	City of Brady		City of Brady
34	Hamilton	Seaboard Oil Co.	1	Dawson	B.B.B. & C.R.R.	Sec. 41
35	Lampasas	Western Lampasas Oil Co.	1	Whittenberg	John Boyd	Block 229, Sec. 38
36	Wichita	Gulf Oil Corp.	43A	Burnette	H.T. & B.R.R.	1,400 ft. from north and 469 ft. from west line of E. ½, Sec. 4
37	Wichita	Shell Oil Co. *et al.*	18E	Preston A	H. & T.C.R.R.	1,165 ft. from south and 2,690 ft. from east line of Sec. 20, Block 7
38	Wichita	Deep Oil Development Co.	1	Munger A	Kemps Wichita Valley Farms Lands	330 ft. from north line and 330 ft. from west line of Sec. 30

and E, described in the following paragraphs, increases northward and northeastward from the Central Mineral region; the thickness of sub-unit B_2 is relatively uniform; unit A and the upper part of sub-unit B_1 of the subsurface are absent in the Central Mineral region.

No fossils were obtained from well cuttings and cores of the subsurface beds. The age determinations of the subsurface subdivisions discussed must be based, therefore, on a lithologic comparison of well cuttings and siliceous residues with the beds exposed in the Central Mineral region where fossils are found. Formation names are not used because insufficient data are available to make precise correlations of the formational units between the subsurface beds and the exposed rocks. However, the subsurface rocks are subdivided tentatively into units, each of which has distinctive lithologic characteristics as revealed by the siliceous residues and the well cuttings. A generalized columnar section and a brief description of the subdivisions are shown in Table I. Correlations of the units and subunits throughout the region are shown in Plates 3 to 10. In the parts of the area that contain more than one well that reached the Lower Ordovician and Upper Cambrian rocks, only those wells for which adequate sets of cuttings were available, and those that penetrated the most subdivisions, were selected for inclusion in these plates.

Units B, C, and D, shown in Table I, correspond with Hendricks'[9] units 1, 2, and 3, unit 4 of his report not being considered a valid subdivision in the light of more recent evidence.

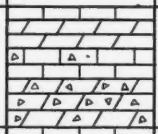
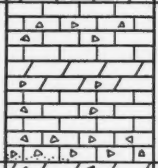
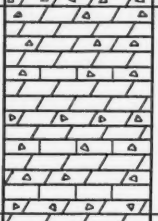
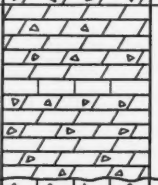
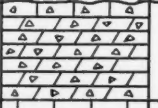
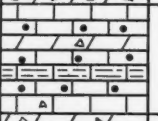
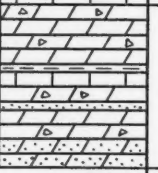
Unit A is composed largely of beds of finely crystalline to granular limestone and dolomite. The insoluble residues obtained from these rocks consist of finely granular silica, white to light brown granular-textured chert, locally oölitic, and some shale and sand. The finely granular silica is the chief distinguishing feature of unit A, for it is encountered only rarely in the other units. Unit A is present only in the eastern part of the region. Of the wells examined, it is present in wells 13, 14, 15, 23, 31, and 27 in Clay, Montague, Denton, Tarrant, and Somervell counties (Pls. 1, 2, 4, 6, 7, and 10). The beds of unit A were preserved in a northward-trending regional syncline that was present as early as Lower Ordovician time. This structural feature has been named the Forth Worth syncline by Sellards.[10]

The thickness of unit A ranges from a feather edge to 490 feet, the maximum having been encountered in A. G. Carter *et al.* Allen well No. 1 in Denton County (No. 23 in Pls. 1, 2, 4, and 6), which stopped in this unit. The thickness is 110 feet in well 13 (Pls. 1, 7, and 10) in Clay County; 60 feet in well 6 (Pls. 1, 2, and 8), and 50 feet in well 14 (Pls. 1 and 7) which stopped in unit A, and 90 feet in well 15 (Pls. 1 and 7), all three in Montague County; 140 feet in well 31 (Pls.

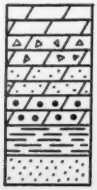
[9] Leo Hendricks, *op. cit.*, pp. 925–29.

[10] E. H. Sellards, "Major Structural Features of Texas East of the Pecos River; Structural and Economic Geology of Texas," *Univ. Texas Bur. Econ. Geol. Bull. 3401* (1934), p. 90.

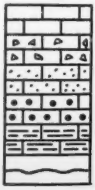
TABLE I. GENERALIZED COLUMNAR SECTION OF SUBSURFACE SUBDIVISIONS OF LOWER ORDOVICIAN AND UPPER CAMBRIAN ROCKS

Subdivisions: Units	Subdivisions: Sub-units	GENERALIZED COLUMNAR SECTION	Maximum known thickness in feet	DESCRIPTION
A			490	Finely crystalline to granular limestone and dolomite. Insoluble residues consist of finely granular silica; white to light brown granular-textured chert, oölitic in some places; and shale and sand
B	B_1		640	Predominantly crystalline to dense limestone and lesser amount of dolomite. Insoluble residues consist characteristically of smooth-textured chert; green and red shale, in part dolomoldic; sand; minor amounts of crystalline and granular-textured chert, and rare grains of glauconite
	B_2		320	Crystalline to dense dolomite and limestone; dolomite predominates at most places. Insoluble residues are similar to those in sub-unit B_1 though their total amount is less in most places. Crystalline and granular-textured chert is more abundant here than in sub-unit B_1
C	C_1		850+	Mainly crystalline to dense dolomite with a few beds of limestone. Siliceous residues consist largely of granular-textured and crystalline chert which is commonly devitrified, dolomoldic and oölitic, ranging from bluish white through lemon-yellow to light brown
	C_2		700+	Crystalline to dense dolomite with rare beds of limestone. Siliceous residues consist characteristically of chalk-textured chert, minor amounts of crystalline and granular-textured chert, and rarely shale
	?	?	?	
D			400	Crystalline to dense dolomite, with some limestone in a few places. Siliceous residues consist primarily of abundantly dolomoldic, granular-textured white to light brown, though ordinarily buff chert
E			440	Predominantly limestone, commonly earthy, and in many places silty and oölitic. Siliceous residues consist predominantly of silt, shale, and minor amounts of sand. Chert is present rarely
F			660	Predominantly dolomite, with some limestone and minor amounts of shale and sandstone. Siliceous residues consist of glauconite, red and green shale, and much sand at base, some smooth and granular-textured chert
		Total	4,500	

EXPLANATION



Dolomite
Cherty dolomite
Sandy dolomite
Oolitic dolomite
Shale
Sandstone



Limestone
Cherty limestone
Sandy limestone
Oolitic limestone
Shaly limestone
Unconformity

1 and 4) in Tarrant County which stopped in unit A; and 95 feet in well 27 (Pls. 1, 2, 4, and 5) in Somervell County.

Unit B consists of beds of limestone and dolomite. Limestone predominates over dolomite in most places, though it is absent in many places. The insoluble residues obtained from beds of unit B consist of smooth-textured chert, green and red shale, some of which is dolomoldic, different proportions of sand, minor amounts of crystalline or granular-textured chert, and rare grains of glauconite. The smooth-textured and crystalline or granular-textured chert ranges in color from white and bluish white to tan; some of it is opaque and some is translucent. The chert contains dolomolds and oölites, and in places it is devitrified.

Unit B is present in all wells shown here in north-central Texas where wells were drilled deep enough to reach the unit, excepting well 17 in King County, well 8 in Foard County, well 36 in Wichita County, well 5 in Clay County, and well 16 in Cooke County. The thickness of unit B ranges from a feather edge to greater than 960 feet. This thickness was penetrated in the M. E. Davis Oil Company's Cousins No. 1 in Somervall County (No. 27 in Pls. 1, 4, and 5) without reaching the base of the unit. The total thickness of unit B is 850 feet in the Sinclair Prairie Oil Company's Doty well No. 2 (No. 6 in Pls. 1, 2, and 8) in Montague County.

The beds of unit B are subdivided largely on the basis of a difference in porosity into an upper and lower unit, called here sub-units B_1 and B_2. The beds of sub-unit B_1 show relatively little porosity, whereas beds of sub-unit B_2 show somewhat higher porosity than B_1, especially where they are unconformably overlain by Paleozoic beds that are younger than sub-unit B_1. Moreover, sub-unit B_2 contains more dolomite than sub-unit B_1 and the residues from B_2 beds contain greater amounts of green or red shale and silt than those from B_1 beds. Although B_2 beds yield a smaller total amount of chert residue, the granular-textured or crystalline chert comprises a larger percentage of the residue from B_2 beds than from B_1 beds. A small amount of sand or sandy dolomite is present at most places at the contact of B_1 and B_2 beds. It is only after considerable acquaintance with these beds that one is able to differentiate the two sub-units at or adjacent to their contact in places where the sandy beds are absent, for this contact then appears to be gradational.

The thickness of sub-unit B_1 is erratic because it has been partly or entirely eroded in many places. The thickness of sub-unit B_2, where it has not been cut by erosion, is more uniform than that of any other unit within the area shown in Plate 1. Its thickness ranges from about 200 to 320 feet. A representative section, where the full thickness of sub-unit B_2 is present, is found in the Sinclair Prairie Oil Company's Doty well No. 2 (No. 6 in Pls. 1, 2, and 8) in Montague County.

Uhit C consists mainly of beds of crystalline dolomite containing subordinate amounts of limestone. Except in its lower part, the residue derived from the unit consist characteristically of granular-textured and crystalline chert, which in

many places contains dolomolds and oölites. Like each of the other subdivisions, unit C is locally absent due to erosion prior to the burial of the sequence here described, by younger beds that range in age from Middle and Lower Ordovician to Pennsylvanian. Except for wells 5 and 8 in Clay and Foard counties (Pls. 1, 7, 8, and 10), all or part of unit C is present in all wells examined that penetrated deep enough to encounter the unit.

Unit C is divided into two sub-units, designated herein as sub-units C_1 and C_2. The upper sub-unit C_1 consists mainly of beds of dolomite though beds of limestone occur in some places. The siliceous residues from these beds characteristically consist of granular-textured and crystalline chert, which commonly is devitrified and is dolomoldic and oölitic. The chert may be clear, blue-white, lemon-yellow, or light brown, transparent, translucent, or opaque. The chert from the lower half of sub-unit C_1 in some places is highly devitrified, making it difficult to differentiate it from the cherts of the next lower sub-unit C_2. The chert has this character in the residues from sub-unit C_1 in the Deep Oil Development Company's Munger No. 1-A (No. 38 in Pls. 1 and 3) in Wichita County. In addition, the residues in some places contain considerable amounts of waxy green shale, and rarely red shale or shale of another color. Sand in varying amounts is present in some places. Sub-unit C_1 is fully developed in the Deep Oil Development Company's Hirschi No. 1 (No. 4 in Pls. 1, 2, 3, and 8) in Wichita County, where it is approximafely 850 feet thick. A thickness of 1,050 feet appears to be present in the Seaboard Oil Company's Dawson No. 1 (No. 34 in Pls. 1 and 4) in Hamilton County, but there is considerable doubt that this represents the true thickness. It is possible that the rocks in the area have been faulted and that the drill actually penetrated some of the beds twice.

Sub-unit C_2 consists predominantly of beds of crystalline to dense dolomite and, in some places, a few beds of limestone. The residues from the sub-unit are characterized by the presence of white chalk-textured chert that is commonly soft and brittle. This chert is associated in many places with minor amounts of crystalline and granular-textured chert. Some shale is present in a few places and sand in some places. It is noteworthy that smooth-textured chert is absent almost everywhere. The greatest thickness of sub-unit C_2 occurs in the Deep Oil Development Company's Hirschi No. 1 (No. 4 in Pls. 1, 2, 3, and 8) in Wichita County, where it is about 400 feet thick.

Unit D consists largely of beds of dolomite, though beds of limestone are present in some places. The siliceous residues from unit D consist mainly of light tan or buff, and locally white to light brown, highly dolomoldic granular-textured, transparent, translucent, or opaque chert. The chert is not devitrified except in places where the beds of unit D are in unconformable contact with Paleozoic rocks younger than unit C. A minor amount of smooth-textured chert is present in a few places. Minor amounts of sand and some shale occur locally, especially in the lower part of the unit. Except for well 8 (Pls. 1 and 7) in Foard County, well 24 (Pls. 1 and 5) in Taylor County, well 25 (Pls. 1, 3, and 5) in Eastland

County, well 32 (Pls. 1 and 3) in Brown County, and well 33 (Pls. 1 and 3) in McCulloch County at least part of unit D is present in all wells that were drilled deep enough to penetrate it. Its thickness is 277 feet in well 26 (Pls. 1 and 5) in Comanche County, and 350 feet in well 5 (Pls. 1, 8, and 10) in Clay County. Its maximum thickness is 400 feet in the Deep Oil Development Company's Hirschi No. 1 (well 4 in Pls. 1, 2, and 3) in Wichita County.

Except for a few places where beds of dolomite are present, unit E consists predominantly of beds of limestone that are commonly oölitic, silty, and have a decided earthy appearance. The residues from these beds characteristically consist of silt and shale and minor amounts of sand. Chert is present in only a few places. Except for well 8 (Pls. 1 and 7) in Foard County, where the sequence was deeply eroded, beds of unit E are present in all wells that were drilled deep enough to penetrate it. The thickness of the unit is 270 feet in well 4 (Pls. 1, 2, 3, and 8) in Wichita County, 150 feet in well 25 (Pls. 1, 3, and 5) in Eastland County, 320 feet in well 33 (Pls. 1 and 3) in McCulloch County, and 230 feet in well 35 (Pls. 1 and 4) in Lampasas County. Its maximum thickness is 440 feet in The Texas Company's Byerts No. 41 (No. 5 in Pls. 1, 2, 8, and 10) in Clay County.

Unit F consists predominantly of dolomite, containing a few beds of limestone and minor amounts of shale and sandstone. Siliceous residues from this unit consist mainly of glauconite and red and green shale. Smooth-textured and granular-textured chert is present locally and in some wells much sand occurs near the base of the unit. Unit F is present in all wells drilled deep enough to reach it. Its thickness is 385 feet in well 25 (Pls. 1, 3, and 5) in Eastland County, and 420 feet in well 33 (Pls. 1 and 3) in McCulloch County. Its greatest known thickness is 660 feet in well 5 (Pls. 1, 2, 8, and 10) in Clay County. Unit F, in the five wells that penetrated it, lies on Cambrian sandstone which, in turn, lies on pre-Cambrian igneous rock, although due to the high relief of the pre-Cambrian surface, it is entirely possible for unit F or even younger units to rest directly on pre-Cambrian rocks.

REGIONAL RELATIONSHIP

The character of the siliceous residues for each unit persists throughout the region investigated. Many of the diagnostic features of each unit can be recognized by an examination of the well cuttings alone, but the writers are convinced that it is necessary to isolate the insoluble residues for examination to make possible a definite recognition of the units.

It was found that attempts to make correlations of the subsurface rocks, based merely on sequence of beds, without taking into account the insoluble residues, invariably led to incorrect conclusions. For example, the relative proportions of dolomite and limestone in any unit varies widely from place to place. Units B and E consist mainly of beds of limestone, and the other units consist mainly of dolomite. Locally, however, unit B consists entirely of dolomite, and units C and F contain large amounts of limestone.

A sequence including all of the units described is believed to be present only in a few areas, as the deposition of these beds was followed by several periods of diastrophism and erosion. At least one period of erosion is believed to have occurred during the interval in which these rocks were deposited. Erosion was particularly severe following the deposition of Mississippian rocks. During this period truncation on the crests of many anticlines reached deeply into this sequence and removed it entirely from some folds. Thus in every place where beds of the Simpson group overlie this sequence, unit A is present, but in places where beds younger than the Simpson group overlie the sequence, any of the units may be encountered below the unconformity.

It is noteworthy that unit D is absent in some places where the units that normally lie next above and below it are present. This relationship exists in Hopkins' Davis well No. 1 (No. 25 in Pls. 1, 3, and 5) in Eastland County, and in J. B. Jameson's Webb well No. 1 (No. 24 in Pls. 1 and 5) in Taylor County. Furthermore, the thickness of unit E in these two wells is less than elsewhere. These facts suggest that a period of erosion followed the deposition of unit D, during which all of unit D, and possibly the upper part of unit E, were removed in places. It is possible that this unconformity marks the boundary between the Cambrian and Ordovician systems.

It is believed that the notable variations in thickness of unit F are due to the irregularities on the surface of the pre-Cambrian rocks underlying it, and in part to lateral gradation between sandstone and sandy dolomite or limestone. Though the unit was found in all wells that encountered units younger than F and were drilled deep enough to reach unit F, it is probable that it is absent locally due to non-deposition on hills of pre-Cambrian rock.

Although the investigation disclosed only a small amount of information concerning the distribution of beds that are sufficiently porous to serve as reservoir beds for oil and gas, it is believed that, except for sub-unit B_1 and possibly unit E, each unit and sub-unit contains porous beds, especially where it has been partly truncated and so directly underlies an unconformity.

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PALEOGEOGRAPHIC AND PALINSPASTIC MAPS

MARSHALL KAY[1]
New York, New York

ABSTRACT

Paleogeographic maps can be prepared to show the distribution of land and sea, geomorphology of the land, depth of the sea, distribution of bottom sediments, directions of currents in water and air, and climatic belts. Isopachous maps present thickness of sediments, and are stratigraphic; their conversion to structural interpretation requires consideration of attendant paleogeography. Paleogeologic maps give further evidence of deformation. Palinspastic maps place rocks in their interpreted positions prior to folding, thrust faulting and flow; paleogeographic and isopachous maps complement structural information in their preparation. Palinspastic base maps of North America for several stages in history are presented; a summary of the controversies respecting major thrust faults emphasizes their subjective nature.

INTRODUCTION

Paleogeography deals with the geography of the geologic past. Comprehensive foreign treatises[2] have considered a wide range of subjects such as normally fall in the fields of sedimentology, stratigraphy, and tectonics. Many facts and interpretations relating to paleogeography can be expressed on maps. One need but leaf the pages of a standard atlas of physical geography to appreciate the limits that might be attained. Geographic maps are of a single time, the present; ideal paleogeographic maps are of a moment in the past. Inasmuch as stratigraphy deals with the development of the earth's surface, comparison of two or more equivalent maps conveys stratigraphic information.

Palinspastics concern the placement of rocks in their relative original positions. The sediments in many regions have been deformed by folding, faulting, and flow, gaining positions differing from those at their deposition. Geographic maps become successively less satisfactory base maps for older and older paleogeographies. Palinspastic maps are paleogeographic base maps; they are essential to proper portrayal of paleogeography. There is no doubt that the rocks had different dispositions, but present knowledge limits the possibility of correct placement. Paleogeographic maps complement structural evidence in preparing reconstruction.

Charles Schuchert, outstanding preparator of paleogeographic maps of the North American continent, published a short article on the problems in their making.[3] The present paper summarizes the types of maps that may be made and their application to stratigraphy and tectonics. It emphasizes the inade-

[1] Professor of geology, Columbia University. Manuscript received, January 3, 1945.

[2] Theodor Arldt, *Palaeogeographie*, Borntraeger, Leipzig (1919, 1922). 2 vols.
Edgar Dacque, *Grundlagen und Methoden der Paläogeographie*, Gustav Fischer, Jena (1915).
Fritz Kerner-Marilaun, *Paläogeographie*, Borntraeger, Berlin (1934).
———, *Paläoklimatologie* Borntraeger, Berlin (1930).
Franz Kossmat, *Paläogeographie und Tektonik*, Borntraeger, Berlin (1936).

[3] Charles Schuchert, "The Making of Paleogeographic Maps," *Leopoldina, Amerikaband*, Vol. 4 (1929), pp. 116–25.

quacy of critical data needed in their preparation. Several palinspastic base maps for North American paleogeography are included. The references are restricted to representative publications, inasmuch as a comprehensive bibliography would be very extended.

PALEOGEOGRAPHIC MAPS

Accuracy.—The accuracy of a paleogeographic map is dependent on the precision of correlation of the stratigraphic units represented. Evidence is rarely sufficiently complete and unequivocal to permit more than approximation. Inasmuch as the cartography is the principal object in the present article, it may be assumed that the material facts bearing on synchroneity have been evaluated properly.

The majority of published maps are of relatively small scale, illustrating concepts or interpretations that are generalizations. Few are truly "geographic" in their showing conditions at a moment of time. Lines are rather accurately placed only in limited areas where the margins of deposits lie within present preservation. Maps on larger scales for small areas give rather accurate delimitations.

Paleogeomorphic maps.—The simplest paleogeographic maps are those separating seas and lands. Hypsometric maps having contours or hachures are used in illustrating present topography. Inasmuch as lands are interpreted chiefly from the deposits gained from their denudation, evidence is rarely sufficient to warrant the use of contours; they might be used in local areas on unconformities having high relief.[4] Increasing numbers of smaller-scale maps employ shading or physiographic symbols to portray concepts of lands. Shore lines of submergence or emergence should be shown by appropriate symbolic shore features rather than with smooth curves.[5]

Paleolithologic and paleobathymetric maps.—Bathymetric maps represent the form of sea floors by isobaths. Rocks preserve many pertinent facts bearing on the depths of waters. Paleolithologic maps have lines, isoliths, connecting points of similar lithology and separating rocks of differing nature.[6] They may be designations of color, texture, or composition[7]; isoliths include such lines of equal abundance or magnitude (isopleths[7a]) as those of equal median sizes (isomega-

[4] C. L. Dake and Josiah Bridge, "Buried and Resurrected Hills of the Central Ozarks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), pp. 629–52.
Marshall Kay, "Ottawa-Bonnechere Graben and Lake Ontario Homocline," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 629–32.

[5] Erwin Raisz, *General Cartography*, McGraw-Hill, New York (1938), pp. 151–53.

[6] W. L. Grossman, "Stratigraphy of the Genesee group of New York," *Bull. Geol. Soc. America*, Vol. 55 (1944), p. 48.

[7] P. B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 734–35, *etc.*
J. M. Hills, "Rhythms of Permian Seas—a Paleogeographic Study," *ibid.*, p. 225, Figs. 4–5, *etc.*, are examples.

[7a] W. C. Krumbein, "Graphic Presentation and Statistical Analysis of Sedimentary Data," *Recent Marine Sediments*, Amer. Assoc. Petrol. Geol. (1939), pp. 587–90.

thies [7b]). To be truly geographic the sediment should be shown as it was prior to diagenesis and metamorphism. Character of sediment can not be converted empirically to depth, but the nature and distribution of textures, characters of bedding, cross-lamination and ripples aid in judgment. Maps of fossil distribution, with evaluation of the habitat of the organisms,[8] add evidence. Thus from the lithology and fauna, it is possible to construct paleobathymetric maps.[9] Paleolithologic and paleobathymetric maps are useful not only as concise summaries of regional records; their applications in interpretations of stratigraphy and structure will be discussed.

Paleoclimatologic and paleooceanographic maps.—An atlas of geography contains maps showing ocean currents and wind directions; evidence of climate is supported further in maps of distribution of vegetation. In the rocks, currents in air and water have oriented organisms, ripple marks, and cross-laminations, as well as distributed lithofacies. Faunal and floral distributions[10] have climatic correlation, as have paleolithologic maps recording pertinent data.

Studies in the orientation of fossils have been few and of limited areas. The orientation of graptolites in the Adirondack area was reported fifty years ago.[11] A classic study on orientation as well as variation is that of Cambrian brachiopods in Nova Scotia.[12] The arrangement of Ordovician orthoceracone cephalopods in two localities illustrates suggestive problems (Fig. 1). Those on St. Joseph Island have two maxima, one each for large and small specimens; one recalls the water-logged sticks paralleling shore, and larger part-floating logs normal to it in fresh-water lakes.

The orientation of ripples has been a subject of some study. There is remarkable consistency in trend of large pararipples in the Mississippian of Ohio.[13] Similar structures in the Ordovician and Silurian silty sandstones have been attributed to off-shore submarine currents.[14] Large ripples in coarse calcite sand-

[7b] F. P. Shepard and G. V. Cohee, "Continental Shelf Sediments Off the Mid-Atlantic States," *Bull. Geol. Soc. America.* Vol. 47 (1936), pp. 443–44, Pl. 3.

[8] M. K. Elias, "Depth of Deposition of the Big Blue (Late Paleozoic) Sediments in Kansas," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 403–32.

[9] Gayle Scott, "Paleoecological Factors Controlling Distribution and Mode of Life of Cretaceous Ammonoids in Texas Area," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 1195.
Ibid., *Jour. Paleon.*, Vol. 14 (1940), p. 318.

[10] R. W. Chaney, "Tertiary Forests and Continental History," *Bull. Geol. Soc. America*, Vol. 51 (1940), p. 485.

[11] Rudolf Ruedemann, "Evidence of Current Action in the Ordovician of New York," *Amer. Geol.*, Vol. 19 (1897), pp. 367–91.
———, "Additional Note on the Oceanic Current in the Utica Epoch," *ibid.*, Vol. 21 (1898), pp. 75–81.

[12] G. F. Matthew, "Cambrian Rocks of Cape Breton," *Geol. Survey Canada Pub. 797* (1903), pp. 52–63.

[13] J. E. Hyde, "The Ripples of the Bedford and Berea Formations in Central and Southern Ohio, with Notes on the Paleogeography of the Epoch," *Jour. Geol.*, Vol. 19 (1911), pp. 257–69.

[14] W. H. Bucher, "On Ripples and Related Sedimentary Surface Forms and Their Paleogeographic Interpretation," *Amer. Jour. Sci.*, 4th ser., Vol. 47 (1919), pp. 258–68.

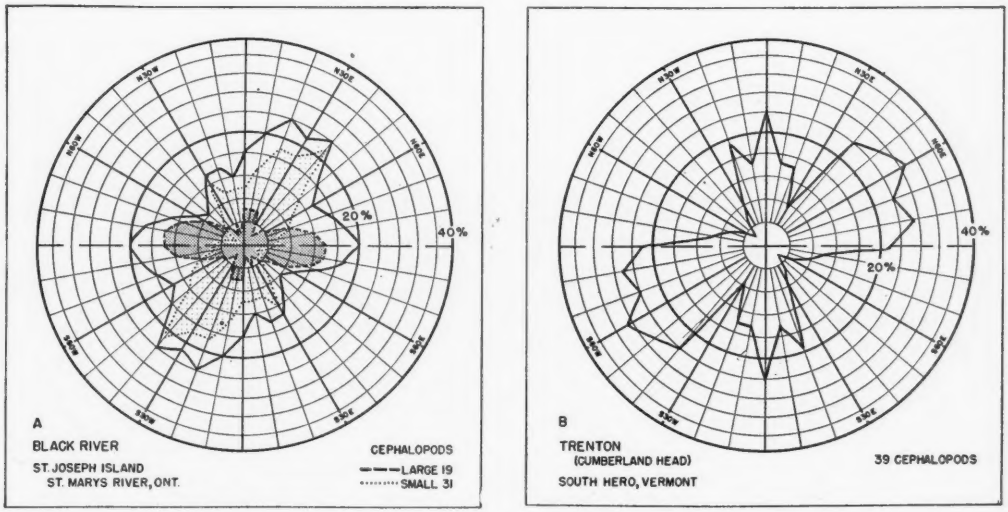

FIG. 1.—Orientation of orthoceracone cephalopods; percentages are of trends within 10° of directional rays. *A*. Black River limestone, Old Quarry Point, near Hilton Beach, St. Joseph Island, Algoma District, Ontario. *B*. Middle Trenton Cumberland Head calcareous shale, north of Rockwell Bay, South Hero Township, Grand Isle County, Vermont.

stones (calcarenites) intercalated in argillaceous limestone in the Ordovician Trenton group in New York and Ontario have distinctive modes changing in direction and number with time (Figs. 2 and 3). They bear on climate if they are the effects of prevailing winds;[15] they relate to coastal trends if they be results of off-shore currents. Other ripples of similar form but in fine calcareous sandstone within deeper-water facies of the Denmark formation[16] (Fig. 4) show slight translation by their cross-lamination; critical study will probably reveal several modes of origin and significance for these large ripples. Cross-lamination in Permian sandstones in Arizona shows distinctive patterns of orientation having significance in the regional stratigraphy.[17] Orientation studies offer a field of investigation that has been neglected, and will yield important paleogeographic results.

ISOPACHOUS MAPS

Isopachous maps illustrate distributions of thicknesses. Inasmuch as they cover a span of time, they are correctly stratigraphic rather than paleogeographic. They are objective only in areas having full preservation of units, but their con-

[15] Marshall Kay, "Stratigraphy of the Trenton group," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 291–92.

[16] Marshall Kay, "Mohawkian Series on West Canada Creek, New York," *Amer. Jour. Sci.*, Vol. 241 (1943), pp. 597–606.

[17] Parry Reiche, "An Analysis of Cross-Lamination; the Coconino Sandstone," *Jour. Geol.*, Vol. 46 (1938), pp. 905–32.

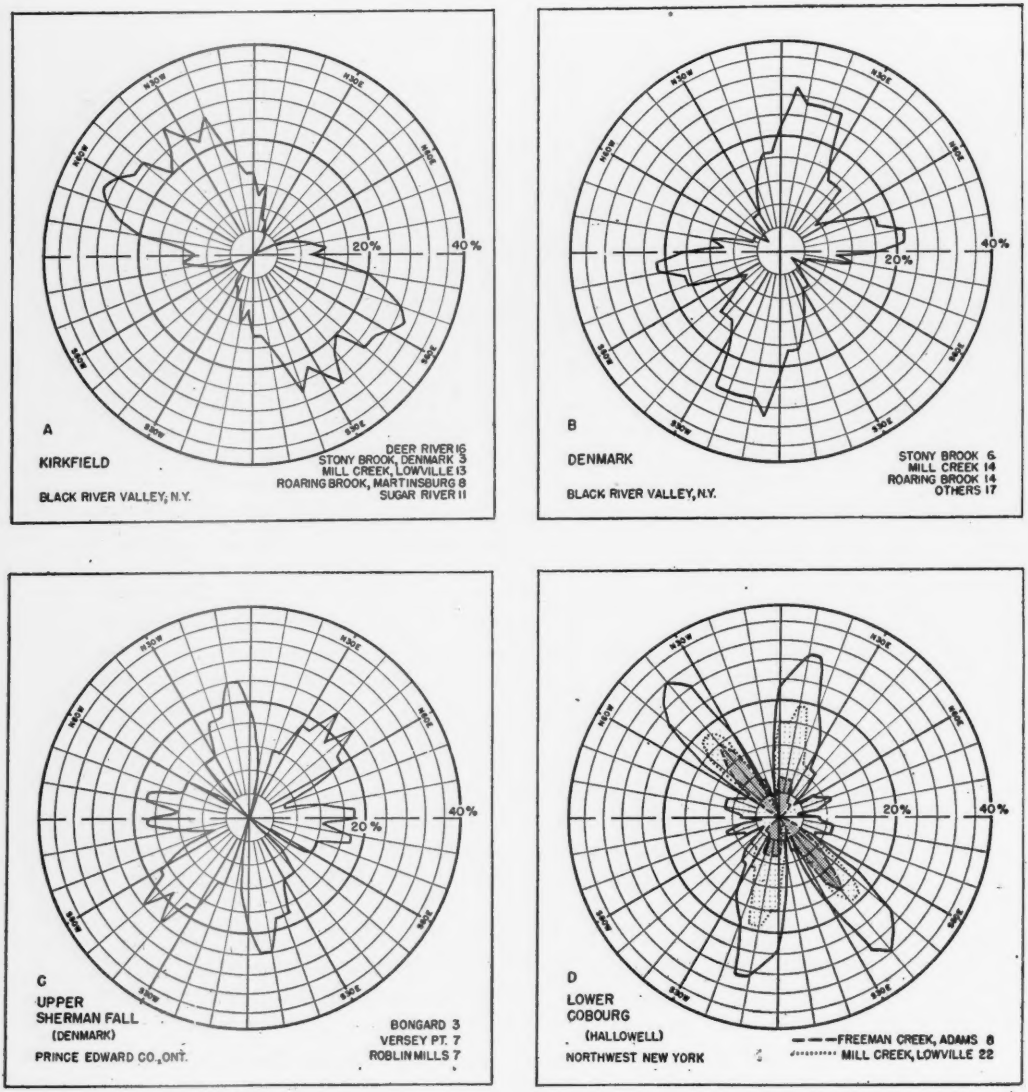

FIG. 2.—Orientation of large ripples in Trenton formation in New York and Ontario; percentages are of trends within 10° of directional rays.

struction permits better judgment of the former extent of sediment, for the solid geometric forms are truncated by present and ancient erosion surfaces. Ultimate knowledge may become greater of older than younger sediments, for their very burial results in broader preservation, though it reduces probability of penetration in wells. Isopachous maps have become so numerous in the past decade that examples need not be cited.

FIG. 3.—Large ripples in lower Trenton Kirkfield limestone below bridge west of Deer River village, Lewis County, New York.

These maps present evidence of warping, epeirogenic movements, but they must be studied cautiously, for there are many factors determining the present thickness of sediments.[18] They are not simply structure-contour maps of a past time, though in most no serious errors result from considering them so; isopachs are not isobases, lines of equal epeirogenic deformation. The exceptions are of such significance that they bear discussion.

Compaction will have reduced thickness, perhaps most where thickness is greatest, but varyingly with facies of differing compositions and textures. Changes in sea-level, eustatic movements, add to or subtract from effects of differential deformation. That the remaining factors be analyzed, the original forms of lower and upper surfaces of reference need consideration. Let us disregard the effects of compaction and eustatic movements in the following discussion. 1. If each refer-

[18] Wallace Lee, "The Stratigraphy and Structural Development of the Forest City Basin in Kansas," *Kansas Geol. Survey Bull. 51* (1943), pp. 98–101.

ence surface was a plane, or a surface of identical form and orientation, isopachs measure vertical movement, and the map, epeirogeny. Maps of units bounded by unconformities or disconformities give an approximate measure of epeirogeny if the surfaces were peneplanes. Whether the upper surface was one of erosional bevelling or non-depositional offlap may be determinable from studies of the

FIG. 4.—Large ripples in middle Trenton Denmark limestone (Russia member) on City Brook, near Middleville, New York.

stratigraphy of the upper beds; the conclusion affects the dating rather than the amount of movement. 2. If the lower and upper surfaces differ, isopachs vary from movement in being too little as the upper surface had greater depth or less elevation than the lower, too great if less depth or greater elevation. The character of the lower and upper surfaces might be expressed on paleobathymetric maps; but lacking these, paleolithologic maps will at least enable better recognition of contrasts.

An extreme example illustrates the need of understanding an isopachous map. In a normal coastal plain (Fig. 5A) the zero isopach is on the continental side, thicknesses increasing to a maximal belt seaward; beyond, they decrease in the finer textures of the ocean depths for great distance. If such a rock mass were raised, and its form restored on an isopachous map, it might seem to evidence a trough between the present land and the oceanic depths (Fig. 5B). The interpreter would reach proper understanding if he recognized the contrast between the continental or shallow-water-laid sediments on the one side with the deep-sea-formed rocks on the other. He would be forced to consider the facies if he prepared paleolithologic maps (Fig. 5C).

Inasmuch as isopachous maps are considerably a record of epeirogeny, whereas paleolithologic maps show the distribution of lithofacies at a surface of deposition affected by the many factors that direct sedimentation, isopachs and isoliths may have quite different patterns. Contrasts in successive isopachous maps are among the most lucid means of revealing changing trends of deformation, and thus of stratigraphic development.

PALEOGEOLOGIC MAPS

"Paleogeologic maps show the areal geology of an ancient surface."[19] They have come into use only in recent years,[20] but are becoming rather frequent, permitting better understanding of regional structure beneath unconformities.[21] Comparison of structural trends evidenced in paleogeologic maps with those shown in properly evaluated isopachous maps of the preceding and succeeding deposits facilitates understanding of the regional deformation.[22]

PALINSPASTIC MAPS

Definition.—Orogenic movements have deformed sediments in many parts of the continent, producing folds and faults, and causing rock flow. The positions of rocks on the present map differ from those at their deposition. Palinspastics concerns the restoration of rocks to their relative original positions. Inasmuch as there has been little lateral movement within the continental interior since the beginning of the Paleozoic, it serves as an excellent area of reference. Ideally, a palinspastic map[23] might show the present lines of outcrop of the time represented moved to their proper initial positions. It is incongruous to show present geo-

[19] A. I. Levorsen, "Studies in Paleogeology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 1107–32.

[20] A. I. Levorsen, "Pennsylvanian Overlap in United States," *ibid.*, Vol. 15 (1931), pp. 142–46.

[21] Workman, L. G., "Subsurface Geology of Chester Series in Illinois," *ibid.*, Vol. 24 (1940), p. 210, for example.

[22] Marshall Kay, "Development of the Northern Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1608.
———, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), p. 99.

[23] Marshall Kay, "Stratigraphy of the Trenton Group," *Bull. Geol. Soc. America*, Vol. 48 (1937), p. 291.

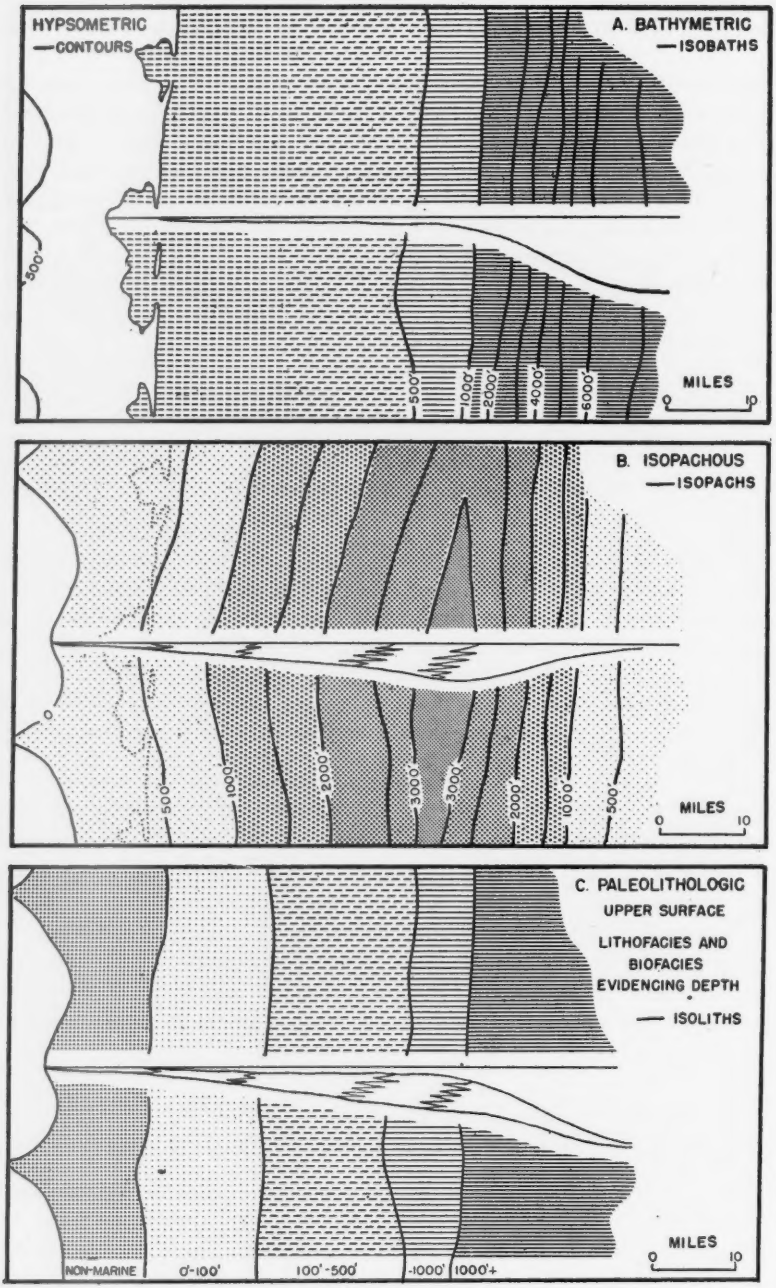

FIG. 5.—Maps and sections of hypothetical coastal area.

graphic, political, and structural lines on the map, for they represent present features; yet they are the reference lines of common experience.

Application.—The purposes and uses of palinspastic maps are several, making varying demands on precision. They have been used to illustrate concepts of continental drift[24] and of intracontinental movements in the development of mountain systems.[25] The difficulties arising in placing continental or regional paleogeography on a geographic base were recognized by Schuchert,[26] who made the seaways of their interpreted original widths but on present geography. By reconstruction of the geographic base, a palinspastic map permits placement of ancient geography in proper relationship to present outcrops.[27] The accompanying palinspastic maps (Figs. 7, 11, and 12) have been made for the purpose of recording continental paleogeography. In their recording later movement, they emphasize correlations betwen stratigraphy and present structure. On somewhat larger scale, in areas where a major overthrust produces two "layers" of facts, separation on a palinspastic base is imperative.

The preparation of the map requires consistent arrangement of folds and faults; methods have been proposed that serve this purpose.[28] Locally, such maps permit better judgment of the nature of the "outcrops" beneath a thrust, and the measurement of the amount of movement.[29] And palinspastic maps present measurably the lateral distortion that has resulted through deformation subsequent to their time, just as structure-contour maps show the vertical changes; they give concrete expression to interpretations of orogenic movement. Maps recording percentages of shortening,[30] and those with lines of equal displacement, isothisms ("iso-ὸthism," from equal and to push) (Fig. 10), also indicate amounts of lateral displacement.

Projection.—The base maps that are presented (Figs. 7, 11, and 12) have been constructed on the sinusoidal projection (Fig. 6); latitudes are parallel, distances on the median longitude and the latitudes are to scale. It is apparent from the angular relations between latitudes and longitudes that distortion is great near the margins in the higher latitudes (Fig. 6), areas in which lines are rarely critical-

[24] Alfred Wegener, *The Origin of Continents and Oceans*, E. P. Dutton, New York (1924), p. 6, *etc.*

A. W. Grabau, *The Rhythm of the Ages*, Henry Vetch, Peking (1940), Pl. 3, *etc.*

[25] E. Argand, "La Tectonique de l'Asie," *Congr. Geol. Intern.*, 13, Compte Rendu 1 (1924), pp. 357–59.

[26] Charles Schuchert, "Orogenic Times in the Northern Appalacians," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 704–05.

[27] Marshall Kay, "Taconic Thrusting and Paleogeographic Base Maps," *Science*, Vol. 82 (1935), pp. 616–17.

[28] A. J. Eardley, "Slotted Template for Resolving Crustal Movements," *Jour. Geol.*, Vol. 47 (1939), pp. 546–54.

[29] R. H. Dott, "Overthrusts in the Arbuckle Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), p. 589.

[30] Ernst Cloos, "Crustal Shortening and Axial Divergence in the Appalachians of Southeastern Pennsylvania and Maryland," *Bull. Geol. Soc. America*, Vol. 57 (1940), p. 847.

FIG. 6.—Outline map of North America, sinusoidal projection.

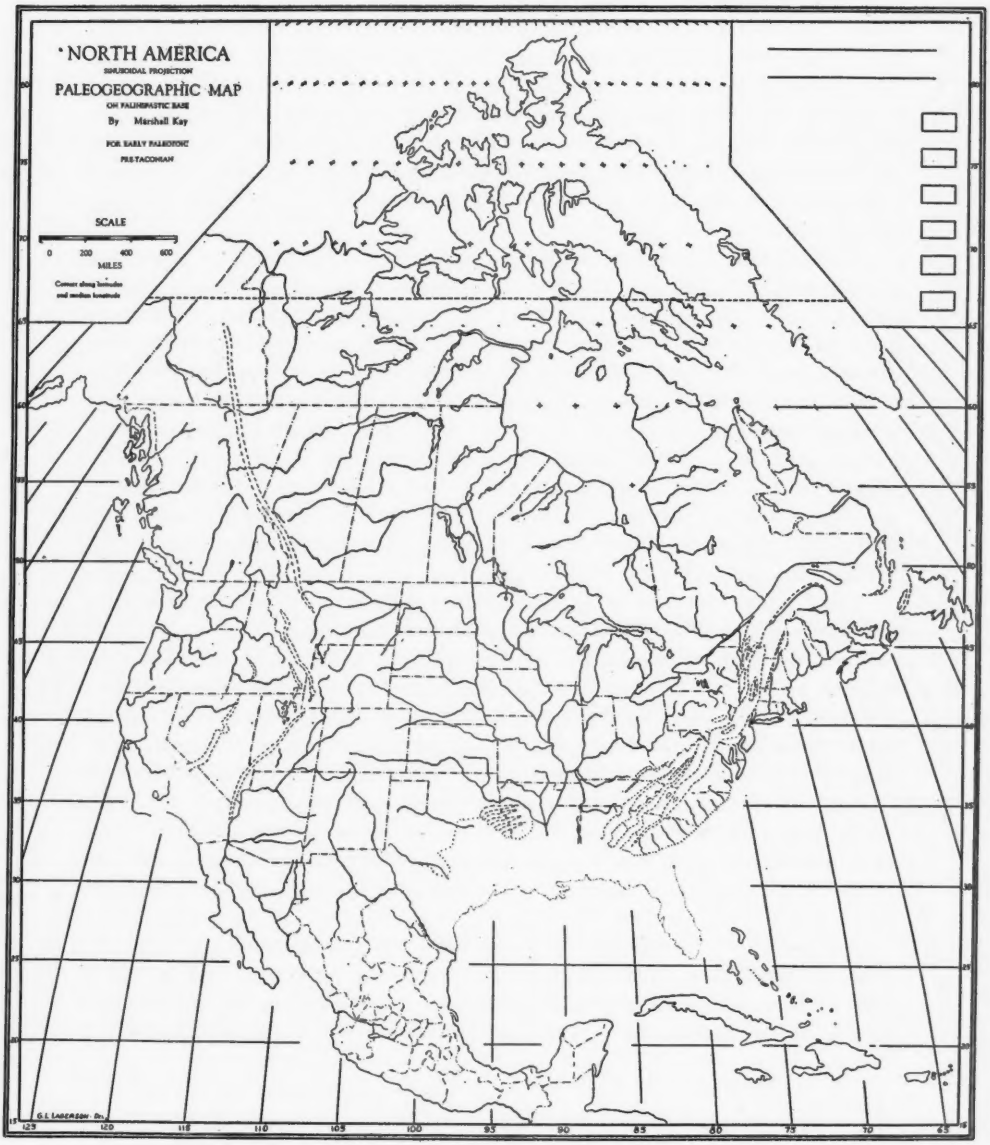

FIG. 7.—Palinspastic outline map for pre-Taconian paleogeography.

ly placed in paleography because information is scanty. The sinusoidal projection is hardly represented among published outline maps of North America, but seems to have distinct advantages. The parallel latitudes create the illusion of flatness in contrast to the seeming concavity in the common projections having northwardly concave arcs. Printed names parallel the principal geographic and political lines. And horizontally lined overprints do not produce interference patterns with the arcuate latitudes, parallel the conspicuous lines on the map. The map is also distinctive in having state and provincial boundaries in Canada, United States, and Mexico.

Preparation.—The accuracy of presentation of displacement is a matter of greater moment. Questions enter with respect to times of deformation, as to amounts, even as to presence. The accompanying maps were prepared as base maps for paleogeography of the continent, the originals printed in quantity with dimensions of about 20 inches, roughly four times those of the reproductions. The scale is so small as to preclude the recognition of folds and thrusts other than those of consideral movement. Allowance has been made in distances in folded belts, though in most cases the scale and lack of local reference detail make the changes obscure. The principal thrusts have been represented with interpreted movement, and are the most striking evidences that the maps are not geographic. Marginally, large areas have been "stretched" rather arbitrarily on the basis of limited evidence that has been presented.

A palinspastic map does not permit compromise such as present limited knowledge would advise. Decisions must be made with recognition that the map can not be correct, and hope that it may approach the truth more nearly than existing maps. The very construction emphasizes the many problems, some of which bear discussion. Too little has been written of the "shortening" in even limited areas; much would be gained if geologists would begin to illustrate judgments on local and regional deformation on palinspastic maps. A reasonable continental map requires the preparation of critical studies in the many parts of the whole. Inasmuch as all deformation is represented on the pre-Taconian, the oldest represented (Fig. 7), it serves best as a reference for subsequent discussion; the maps of the later times will be in error not only in their measurements of deformation but in the dating of events.

Folds.—The determination of the amount of "shortening" in simple folds offers relatively little difficulty, involving the preparation of scale sections of key beds, and comparison of their lengths with the present length of section. Yet there have been few careful studies of sections,[31] or of areas,[32] and one finds insufficient

[31] R. T. Chamberlin, "The Appalachian Folds of Central Pennsylvania," *Jour. Geol.*, Vol. 18 (1910), pp. 228–50.
"The Building of the Colorado Rockies," *ibid.*, Vol. 27 (1919), pp. 145–64, 225–51.

[32] Ernst Cloos, "Crustal Shortening and Axial Divergence in the Appalachians of Southeastern Pennsylvania and Maryland," *Bull. Geol. Soc. America*, Vol. 51 (1904), pp. 845–72.

data in most areas to permit more than generalization. In the preparation of a small-scale palinspastic map, the quantities are so small that detailed knowledge would not be evidenced. Error increases when the sediments enter regions having rock flow;[32a] where moderate, the effect on measurement of stratigraphic thickness on the construction of isopachous maps is more serious than on palinspastic maps, though hardly to the degree that sections "do not permit deductions of any kind which assume that present thickness equals or resembles the thickness prior to folding."[33] Where rocks are severely folded and metamorphosed, estimates can not be more than reasonable judgments, for the geologist is unable to plot all minor structures. In all cases, folding affects not only the distances between belts of outcrop, but their trends, and positions relative to the interior of the connent.

Overthrusts.—Estimation of horizontal displacement along thrust planes becomes more difficult. Where they represent rupture of local folds, errors will not be significantly great. The problems of major overthrusts have led to some of the greatest controversies in North American geology. To some degree these are due to failure to utilize properly stratigraphic evidence in the solution, but in part to assumption that stratigraphic evidence requires explanation in a specific fashion. There is small satisfaction in knowing that each particle of rock did have some initial position different than of to-day.

Statements with regard to displacement are commonly minima based on stratigraphic section cut out by the fault, or the distance from the front of salients and klippen of the thrust sheet to re-entrants or fensters in the rear of the allochthonous rocks. Measurement of sections presenting interpretation of the concealed structure approach the true displacement more closely. When folds that were initiated prior to thrusting are present both below and above the thrust, displacement of their axes can be used. Paleogeographic evidence may prove informative when the facts are known.

Whenever linear elements, such as isoliths and isopachs, can be plotted on both sides of a thrust line, amount of slip may be determinable. A palinspastic map is prepared for each side of the thrust line (Figs. 8 and 9), with paleogeographic lines introduced. Solution is then based on reasonable adjustment of the linear elements of the two parts of the original map. Evidence of several sorts and times may be available, and enhance probability of reasonable solution; anomalies and inconsistencies will require further analysis. Information of these sorts is hardly ever available at the present time; in many cases significant data will never be obtainable. But the use of paleogeographic maps in solving problems of overthrusts offers possibilities.

[32a] W. H. Bucher, *Deformation of the Earth's Crust*, Princeton Univ. Press (1933), pp. 223–30.

[33] Ernst Cloos, "Distortion of Stratigraphic Thicknesses Due to Folding," *Proc. Nat. Acad. Sci.*, Vol. 28 (1942), pp. 401–07.

The allochthones.—An allochthone is the rock of a thrust sheet that has travelled so far that some of the rocks differ markedly from equivalent beds in the tectonically underlying autochthone. Thus, in central Nevada[34] an allochthone of chert- and volcanic-bearing Lower Ordovician slates lies on a thrust plane succeeding an autochthone containing Lower Ordovician carbonates. The easternmost salients of the allochthone extend 16 miles beyond the westernmost mapped

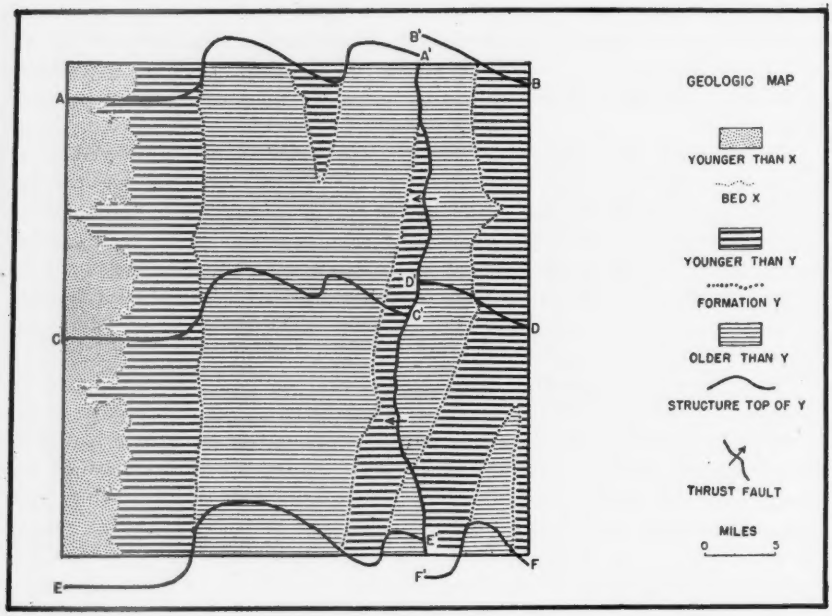

FIG. 8.—Geologic map of an hypothetical area of folded and faulted sediments.

areas of autochthone, a measure of "minimum" displacement; the actual distance was as much greater as the distance originally separating the two points in the contrasting lithofacies. Thus, the estimate of movement is to be based in part on judgment; contrasts in sediments of allochthone and autochthone are normally too great to allow more than general application of the criteria here outlined. Classification of rocks above a thrust as an allochthone is also somewhat arbitrary, depending on how much difference is considered "marked"; where two

[34] C. W. Merriam and C. A. Anderson, "Reconnaissance Survey of the Roberts Mountains, Nevada," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1675–1728.

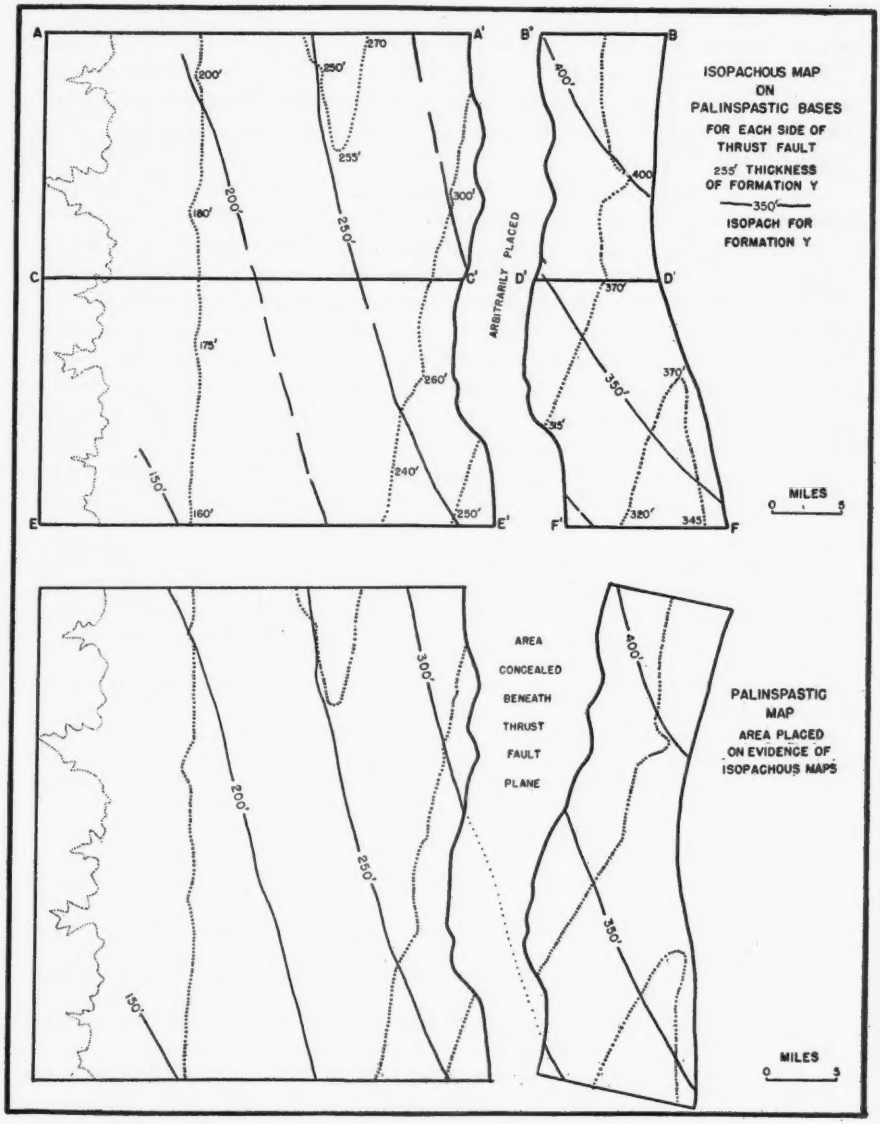

FIG. 9.—Palinspastic maps of hypothetical area of Figure 8.

stratigraphic provinces are involved, there will be little debate. Moreover, inasmuch as every thrust must terminate, contrasts will disappear along the fault line.

Allochthone and autochthone carry stratigraphic implications; allochthonous and autochthonous are adjectives having different connotation, referring to the relatively transported overthrust rocks as compared with the relatively unmoved rocks beneath them.

The problems of major thrust sheets have engendered some of the most protracted controversies in American geology. They have been influenced by views as to what constitutes evidence; structural criteria are emphasized by some, stratigraphic by others. That many of the rocks are metamorphosed increases the difficulties, confusing the stratigraphic sequences, limiting the use of faunas and obscuring the significant structures. As a result, there are divergent judgments or suggestions on the presence or absence of thrusts, the magnitude of displacements, and the times of movement. As preparation of a palinspastic base map for the early Paleozoic requires definite placement of rocks, it is influenced by the selection of authority. The thrust lines are the most obvious indications that the map is palinspastic, and the displacements are strikingly shown as compared with the extension of folded rocks. A summary will emphasize the subjective character of the map.

Taconian thrusts.—Post-Ordovician Taconian thrusts are shown from Newfoundland to Alabama. The map (Fig. 7) conforms to the views of those who have considered them to be present and significant, though in most cases competent authorities support opposing interpretations. There is not unequivocal evidence that any of the thrusts is of that age,[35] though most have been so classified.

In northwestern Newfoundland there are certainly post-Carboniferous thrusts of moderate displacement;[36] it is "well within the realm of possibility" that there are Taconian thrusts of great displacement that can account for seemingly anomalous stratigraphy along the coast[37] in a sequence containing conglomerate with large "exotic boulders" attributed to "talus and landslides formed along a fault scarp that came into existence during mid-Ordovician orogeny . . . formed at the nose of thrust sheets."[38]

A major thrust along the St. Lawrence was recognized nearly a century ago by Logan;[39] evidence is conclusive of "large-scale thrusting involving the transport of sedimentary formations from one province of deposition into another."[40] The area is classic

[35] Arthur Keith, "Structural Symmetry of North America," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 360–61.

[36] Frederick Betz, Jr., "Late Paleozoic Faulting in Western Newfoundland," *ibid.*, Vol. 54 (1943), pp. 687–706.

[37] Helgi Johnson, "Paleozoic Lowlands of Northwestern Newfoundland," *Trans. New York Acad. Sci.*, 2nd ser., Vol. 3 (1941), pp. 141–45.

[38] Charles Schuchert and C. O. Dunbar, "Stratigraphy of Western Newfoundland," *Geol. Soc. America Spec. Paper 1* (1934), pp. 84–86.

[39] William Logan, "Considerations Relating to the Quebec Group and the Upper Copper-Bearing Rocks of Lake Superior," *Canad. Nat.*, Vol. 6 (1861), pp. 199–207.

[40] E. B. Bailey, L. W. Collet, and R. M. Field, "Paleozoic Submarine Landslips Near Quebec City," *Jour. Geol.*, Vol. 36 (1928), pp. 577–614.

because of the "exotic boulders" in the Lower Ordovician shales.[41] It is generally accepted that a major thrust borders the west side of the Taconic Range from Vermont to the vicinity of Albany, New York.[42] Keith originally proposed that the rocks at the north

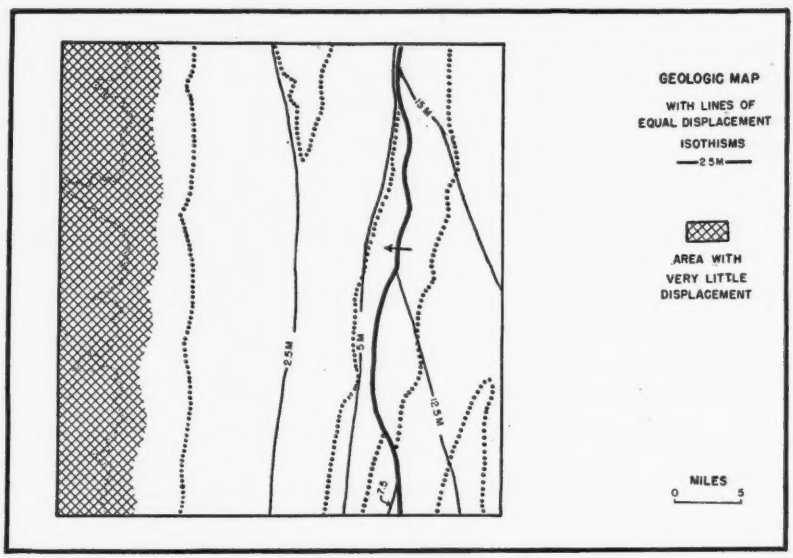

FIG. 10.—Outline of geologic map of Figure 8 with lines of equal displacement.

end of the range form part of an allochthone,[43] a judgment substantiated by subsequent studies,[44] though the root of the thrust has not been determined conclusively.[45] The view that the range has klippe-structure has been advanced for an area southward to the High-

[41] T. H. Clark, "The Paleontology of the Beekmantown Series at Lévis, Quebec," *Bull. Amer. Paleon.*, Vol. 10, No. 41 (1924).
Franco Rasetti, "Upper Cambrian Trilobites from the Lévis Conglomerate," *Jour. Paleon.*, Vol. 18 (1944), pp. 229–58.

[42] Rudolf Ruedemann, "Geology of the Capital District," *New York State Mus. Bull. 285* (1930), pp. 130–51.

[43] Arthur Keith, "Further Discoveries in the Taconic Mountains" (abstract), *Bull. Geol. Soc. America*, Vol. 24 (1913), p. 680.

———, "Stratigraphy and Structure of Northwestern Vermont," *Jour. Washington Acad. Sci.*, Vol. 22 (1932), p. 364.

[44] W. M. Cady, "Stratigraphy and Structure of West-Central Vermont," *Bull. Geol. Soc. America*, Vol. 56 (1945), in press.

[45] H. E. Hawkes, Jr., "Roots of the Taconic Thrust in West-Central Vermont," *ibid.*, Vol. 52 (1941), pp. 649–66.

lands,[46] and expressed on palinspastic maps.[47] Others deny the presence of significant thrusting in the southern part of the argillite belts;[48] the interpretation of great overthrusting is influenced by belief that the argillite facies was laid east of the carbonate facies of the lower Paleozoic. Middle Ordovician conglomerate in the vicinity of Albany contains boulders that have been considered exotic.[49] There are significant thrusts in the upper Connecticut Valley farther east that are younger than Lower Devonian.[50]

Discussion of the Martic thrust[51] in Pennsylvania and southwestward has been more voluminous. The problems are similar to those in the Taconic area, with the views of the protagonists[52] and antagonists[53] differing even as to the presence of a significant thrust. Though there has been general assumption that the structures are late Paleozoic Appalachians, comparison with areas to the north suggests that they may be Taconian and of great magnitude.[54]

Appalachian thrusts.—Of the thrusts in the southern Appalachians, the Saltville-Helena seems stratigraphically most significant, and has been designated as margining the late Paleozoic Appalachian allochthone;[55] it has been mapped from its concealment

[46] E. B. Knopf, "Some Results of Recent Work in the Southern Taconic Area," *Amer. Jour. Sci.*, 5th ser., Vol. 14 (1927), pp. 429–58.
L. M. Prindle and E. B. Knopf, "Geology of the Taconic Quadrangle," *Amer. Jour. Sci.*, 5th ser., Vol. 29 (1932), pp. 258–302.

[47] Marshall Kay, "Stratigraphy of the Trenton Group," *Bull. Geol. Soc. America*, Vol. 48 (1937), Pl. 5.
———, "Development of the Northern Allegheny Synclinorium and Adjoining Regions," *ibid.*, Vol. 53 (1942), p. 1606.

[48] Robert Balk, "Structural and Petrologic Studies in Dutchess County, New York. Part I. Geologic Structures of the Sedimentary Rocks," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 685–774.
Rudolf Ruedemann, "Notes on Ordovician Plankton and Radiolarian Chert of New York," *New York State Mus. Bull. 327* (1942), pp. 45–72.

[49] Rudolph Ruedemann, "Trenton Conglomerate of Rysedorph Hill, Rensselaer County, New York and Its Fauna," *New York State Mus. Bull. 49* (1901), pp. 3–114.

[50] M. P. Billings, "Regional Metamorphism of the Littleton-Moosilauke Area," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 463–566.
J. H. Eric, W. S. White, and J. B. Hadley, "Monroe Fault of New Hampshire and Vermont" (abstract), *ibid.*, Vol. 52 (1941), p. 1900.

[51] E. B. Knopf and A. I. Jonas, "Geology of the McCalls Ferry-Quarryville District, Pennsylvania," *U. S. Geol. Survey Bull. 799* (1929), pp. 74–77.

[52] A. I. Jonas, "Geologic Reconnaissance in the Piedmont of Virginia," *Bull. Geol. Soc. America*, Vol. 38 (1927), pp. 837–46.
———, "Structure of the Metamorphic Belt of the Southern Appalachians," *Amer. Jour. Sci.*, 5th ser., Vol. 24 (1932), pp. 228–43.
G. W. Stose and A. J. Stose, "Geology of the Hanover-York District, Pennsylvania," *U. S. Geol. Survey Prof. Paper 204* (1944), pp. 72–73.

[53] B. L. Miller, "Age of the Schists of the South Valley Hills, Pennsylvania," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 715–56.
J. H. Mackin, "The Problem of the Martic Overthrust and the Age of the Glenarm Series in Southeastern Pennsylvania," *Jour. Geol.*, Vol. 43 (1935), pp. 356–80.
Ernst Cloos, "Geology of the 'Martic Thrust' and the Glenarm Series in Pennsylvania and Maryland," *Geol. Soc. America Spec. Paper 35* (1941), pp. 1–138, 186–207.

[54] Marshall Kay, "Taconic Allochthone and the Martic Thrust," *Science*, Vol. 94 (1941), p. 73.

[55] Marshall Kay, "Development of the Northern Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1647–48.

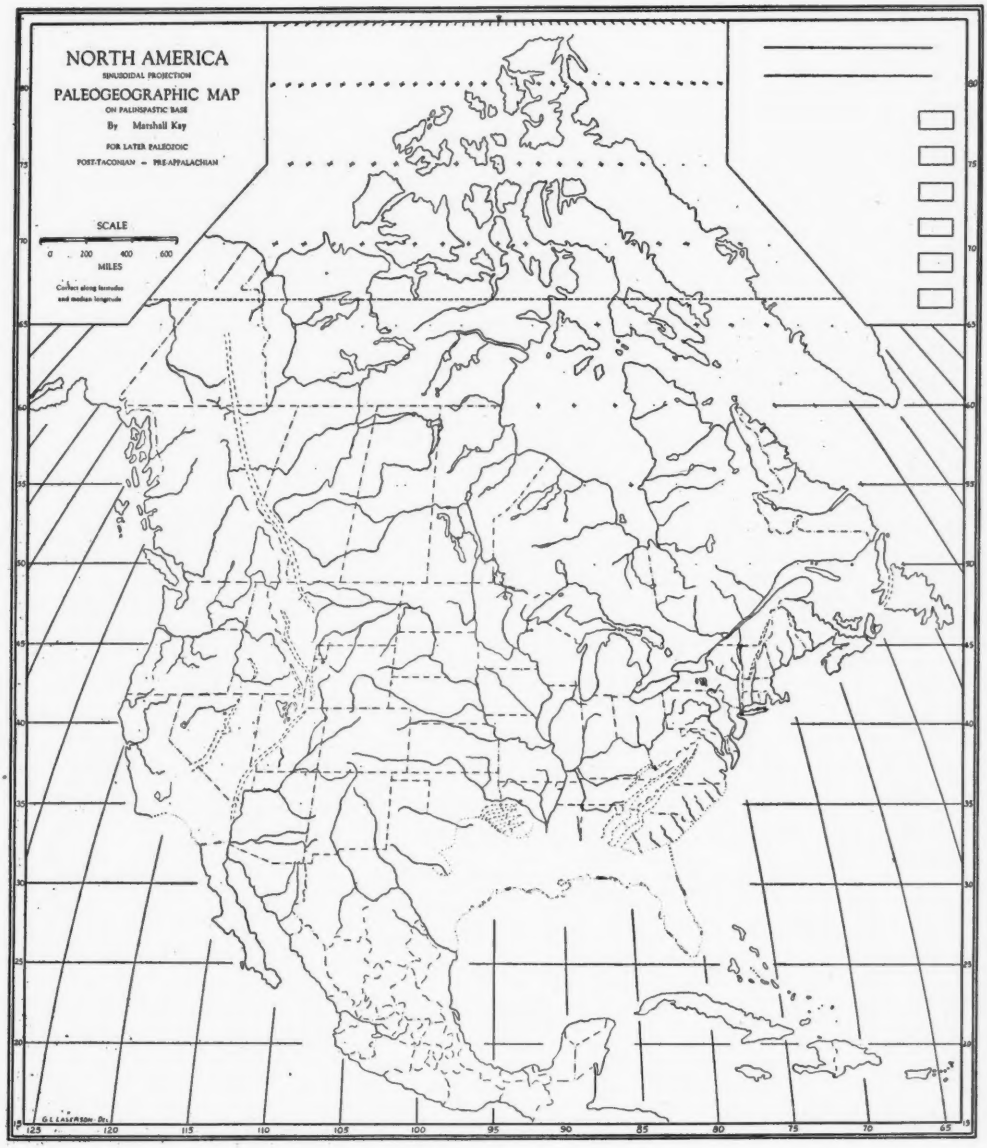

FIG. 11.—Palinspastic outline map for pre-Appalachian paleogeography.

beneath the Coastal Plain in Alabama[56] to its termination in Craig County, Virginia.[57] The contrast in the stratigraphy on the two sides of the Helena fault in Alabama led to the placing of a "barrier," though the probability of magnitude of displacement as a principal cause of differences was advanced later.[58] There are other thrusts of comparable if not greater displacement within the allochthone;[59] and similar overthrusts southeast of the Saltville thrust and its extension in Virginia.[60] In the autochthone, some, such as the Pine Mountain thrust bounding the Cumberland thrust block, have received critical study.[61] All these faults have been classified as late Paleozoic Appalachian.

The Ouachita Mountains of Oklahoma and Arkansas have an allochthone of Pennsylvanian and older rocks on the west passing into strongly folded sediments on the east;[62] the disturbances are middle Pennsylvanian or younger, and thus broadly of the Appalachian orogeny. The "exotic" boulders in the allochthone have attracted a great deal of study.[63] The interpretation that the allochthone continues in the subsurface into Texas[64]

[56] Charles Butts, "Geology of Alabama: Paleozoic Rocks," *Alabama Geol. Survey Spec. Rept. 14* (1926), p. 105.

[57] *Idem*, "Geology of the Appalachian Valley in Virginia, Part I," *Virginia Geol. Survey Bull. 52*, 1940 (1942), p. 457.

[58] van der Gracht, W. A. J. M. van W., "The Permo-Carboniferous Orogeny in South Central United States," *K. Akad. Wetensch. Amsterdam*, Afd. Naturk., 2nd sec., Deel 27, No. 3, p. 111.

[59] G. W. Crickmay, "Status of the Talladega Series in Southern Appalachian Stratigraphy," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 1371–92.

G. W. Stose and A. J. Stose, "The Chilhowee Group and Ocoee Series of the Southern Appalachians," *Amer. Jour. Sci.*, Vol. 242 (1944), pp. 370–73.

[60] H. P. Woodward, "Geology and Mineral Resources of the Roanoke Area, Virginia," *Virginia Geol. Survey Bull. 34* (1932), pp. 80–88.

B. N. Cooper and J. C. Haff, "Max Meadows Fault Breccia," *Jour. Geol.*, Vol. 48 (1940), pp. 945–74.

L. W. Currier, "Zinc and Lead Region of Southwestern Virginia," *Virginia Geol. Survey Bull. 43* (1935), pp. 50–64.

Charles Butts, "Geology of the Appalachian Valley in Virginia. Part I," *ibid.*, *Bull. 52*, 1940 (1942), pp. 440–56.

[61] C. K. Wentworth, "Russell Fork Fault of Southwest Virginia," *Jour. Geol.*, Vol. 29 (1921), pp. 351–69.

Charles Butts, "Fensters in the Cumberland Overthrust Block in Southwestern Virginia," *Virginia Geol. Survey Bull 28* (1927), pp 1–27.

J. L. Rich, "Mechanics of Low-Angle Thrust Faulting as Illustrated by the Cumberland Thrust Block, Virginia, Kentucky and Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1584–96.

[62] H. D. Miser, "Relation of Ouachita Belt of Paleozoic Rocks to Oil and Gas Fields of Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1059–77.

T. A. Hendricks, "Structure of the Western Part of the Ouachita Mountains" (abstract), *Oil and Gas Jour.*, Vol. 38, No. 48 (1940), pp. 45–46.

[63] J. A. Taff, "Some Erratic Boulders in Middle Carboniferous Shale in Indian Territory" (abstract), *Science*, Vol. 21 (1905), p. 225.

E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them," *Oklahoma Geol. Survey Bull. 45* (1927).

W. B. Kramer, "Boulders from Bengalia," *Jour. Geol.*, Vol. 41 (1933), pp. 590–621.

R. C. Moore, "The Origin and Age of the Boulder-Bearing Johns Valley Shale in the Ouachita Mountains of Arkansas and Oklahoma," *Amer. Jour. Sci., 5th ser.*, Vol. 27 (1934), pp. 432–53.

H. D. Miser, "Carboniferous Rocks of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 992–1009.

B. H. Harlton, "Stratigraphy of the Bendian of the Oklahoma Salient of the Ouachita Mountains," *ibid.*, Vol. 22 (1938), pp. 893–900.

has been represented on a generalized palinspastic map.[65] In West Texas, overthrusts of similar trend are exposed in a limited area in Brewster County,[66] affecting pre-Permian sediments having "exotic" boulders in Ordovician and Pennsylvanian beds.

Possible Nevadian thrusts.—The Nevadian orogeny took place within the latest Jurassic.[67] A belt of thrusts shown on the palinspastic map from southern Nevada to western Idaho may be of this age, though conclusive evidence has not been presented. There is an overthrust in central Nevada that has great displacement and forms an allochthone;[68] it is younger than some of the Carboniferous and older than the Tertiary intrusive rocks. Southwestward in the same trend are major overthrusts that affect Jurassic sediments.[69] The third area of major thrusts that is considered to be in the belt is that in south-central Idaho,[70] the youngest affected sediments being Carboniferous. Just north of the International Boundary, west of Kootenay Lake, British Columbia, Late Paleozoic and Triassic cherty slates and volcanic rocks overlie the Windermere series, which has been considered pre-Cambrian.[71] Although this contact was believed at one time to be a thrust fault,[72] later studies have concluded that it is an unconformity,[73] a disposition followed on the palinspastic map. Recent mapping in Washington[74] indicates that the lower part of the Windermere series is Cambrian; the possibility must be entertained that the higher part including beds thought to be infolded Carboniferous extends through much of the Paleozoic.

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[64] H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), pp. 801–18.
T. A. Hendricks, "Structural Interpretation of Recent Gravity Observations in Southeastern Oklahoma," *ibid.*, Vol. 24 (1940), pp. 2143–49.

[65] R. E. Rettger, "Interpretation of Grain of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), pp. 486–90.

[66] P. B. King, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937).

[67] N. L. Taliaferro, "Franciscan-Knoxville Problem," *Bull. Amer. Assoc. Petrol. Geol.*, Vol 27 (1943), pp. 109–219.

[68] C. W. Merriam and C. A. Anderson, "Reconnaissance Survey of the Roberts Mountains, Nevada," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1675–1728.

[69] S. W. Muller and H. G. Ferguson, "Mesozoic Stratigraphy of the Hawthorne and Tonopah Quadrangles, Nevada," *ibid.*, Vol. 50 (1939), pp.1573–1624.

[70] J. B. Umpleby, L. G. Westgate and C. P. Ross, "Geology and Ore Deposits of the Wood River Region, Idaho," *U. S. Geol. Survey Bull. 814* (1930).
C. P. Ross, "Correlation and Interpretation of Paleozoic Stratigraphy in South-Central Idaho," *Bull. Geol. Soc. America*, Vol. 45 (1934), pp. 937–1000.

[71] H. M. A. Rice, "Nelson Map-Area, East Half, British Columbia," *Geol. Survey Canada Mem. 228* (1941), pp. 14–24, 30–31.
J. F. Walker, "Geology and Mineral Deposits of Salmo Map-Area, British Columbia," *ibid.*, *Mem. 172* (1934), pp. 3–10.

[72] C. W. Drysdale, "Slocan Area, Ainsworth and Slocan Mining Divisions," *Geol. Survey Canada Summ. Rept. for 1916* (1917), pp. 56–57, map.

[73] C. E. Cairnes, "Slocan Mining Camp, British Columbia," *Geol. Survey Canada Mem. 173* (1934), pp. 36–38.
J. F. Walker, M. F. Bancroft, and A. C. Gunning, "Lardeau Map-Area," *ibid.*, *Mem. 161* (1929), pp. 12–14.

[74] C. F. Park, Jr., and R. S. Cannon, Jr., "Geology and Ore Deposits of the Metaline Quadrangle, Washington," *U. S. Geol. Survey Prof. Paper 202* (1943).

FIG. 12.—Palinspastic outline map for pre-Nevadian paleogeography.

Laramian overthrusts.—The major overthrusts of the late Cretaceous to early Tertiary Laramian orogeny are in a belt from southern Nevada to western Alberta.[75] In southern Nevada they have great displacement,[76] were forming within the late Cretaceous.[77] Those in Utah have been critically analyzed;[78] two conflicting alternatives are that there is a thrust sheet of great displacement, and that there are thrusts diverging from an "orogen"; evidence is inconclusive, and the latter interpretation is shown on the palinspastic base maps. The overthrusts of southeastern Idaho and southwestern Wyoming form an arcuate salient.[79] Similar thrusts have been described in southwestern Montana;[80] isopachous studies of the Cambrian in the region have suggested the magnitude of movement.[81] The Lewis overthrust of northwestern Montana[82] is the best known in America, and seems of the early Tertiary.[83] It has been mapped for more than 100 miles in Montana,[84] and continues northward into Alberta.[85] In the latter area are multiple thrusts of smaller displacement within the synclinorium adjoining the overthrust.[86]

There are many thrust faults within the sediments east of the belt of major overthrusts. Most are of relatively small throw and limited continuity, but a few have been considered to have great displacement. Of these latter, the Heart Mountain thrust[87] has been considered significant by some,[88] a conclusion that is debated.[89] None of the foreland thrusts has been shown on the palinspastic map.

[75] Arthur Keith, "Structural Symmetry in North America," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 333–34.

[76] C. R. Longwell, "Geology of the Muddy Mountains, Nevada," *U. S. Geol. Survey Bull. 798* (1928), pp. 103–25.

[77] C. R. Longwell, "Muddy Mountains, Nevada, Belt of Thrusting Restudied" (abstract)' *Bull. Geol. Soc. America*, Vol. 52 (1941), p. 1920.

[78] A. J. Fardley, "Geology of the North-Central Wasatch Mountains, Utah," *ibid.*, Vol. 55 (1944), pp. 819–94.

[79] G. R. Mansfield, "Structure of the Rocky Mountains in Idaho and Montana," *Bull. Geol. Soc. America*, Vol. 34 (1923), pp. 263–84.
———, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 1–409.

[80] W. H. Emmons and F. C. Calkins, "Geology and Ore-Deposits of the Philipsburg Quadrangle, Montana," *U. S. Geol. Survey Prof. Paper 78* (1913), pp. 146–50.

[81] Christina Lochman and Donald Duncan, "Early Upper Cambrian Faunas of Central Montana," *Geol. Soc. America Spec. Paper 54* (1944), p. 17.

[82] Bailey Willis, "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. America*, Vol. 13 (1902), pp. 305–52.

[83] M. P. Billings, "Physiographic Relations of the Lewis Overthrust in Northern Montana," *Amer. Jour. Sci.*, 5th ser., Vol. 35 (1938), pp. 260–72.

[84] Charles Deiss, "Stratigraphy and Structure of Southwest Saypo Quadrangle, Montana," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 250–51.

[85] G. S. Hume, "Waterton Lakes-Flathead area, Alberta and British Columbia," *Geol. Survey Canada Summ. Rept. 1932*, Pt. B (1933), pp. 7B–12B.
B. N. MacKay, "Geology and Coal Deposits of the Crowsnest Pass Area, Alberta," *ibid.*, pp. 31B–36B.

[86] B. F. Hake, Robin Willis, and C. C. Addison, "Folded Thrust Faults in the Foothills of Alberta," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 291–334.

[87] C. L. Dake, "The Heart Mountain Overthrust and Associated Structures in Park County, Wyoming," *Jour. Geol.*, Vol. 26 (1916), pp. 47–55.

[88] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geol.*, Vol. 28 (1920), pp. 536–57.

CONCLUSIONS

Many paleogeographic maps have been published; few are "geographic" in showing relations at a single time. Systematic recording of trends of fossils and of primary sedimentary structures and more critical analysis of lithofacies will increase knowledge of ancient geographies. Isopachous and paleogeologic maps are of such obvious utility that they appear in increasing numbers; comparative paleogeographic studies aid in their interpretation. Palinspastic maps portray amounts of lateral movement; they are most valuable in areas of great disturbance. Their preparation encourages better analysis of folds and thrust faults; geographic and isopachous maps assist in their making. Comprehension of the events in the enormous span of geologic history will require many maps of varied kinds.

W. G. Pierce, "Heart Mountain and South Fork Thrusts, Park County, Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25 (1941), pp. 2021–45.

[89] W. H. Bucher, "Remarkable Local Folding Due to Gravity Bearing on the Heart Mountain Thrust Problems" (abstract), *Proc. Geol. Soc. America for 1934* (1935), p. 69.

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GEOLOGICAL NOTES

TYPE SECTION OF ELLIS FORMATION (JURASSIC) OF MONTANA[1]

W. A. COBBAN,[2] R. W. IMLAY,[3] AND JOHN B. REESIDE, JR.[3]

The Ellis formation was named by Peale[4] in 1893 and was described by Iddings and Weed[5] in 1894, and by Peale[6] in 1896. It was intended to include Upper Jurassic marine rocks lying between rocks then designated as the Quadrant formation below and the Dakota formation above (now known to include the Morrison and Kootenai formations) in the general area between Livingston and Three Forks, Montana. It was named after Fort Ellis, about 3 miles east of Bozeman, but no type section was designated.

In September, 1944, the present writers examined the Ellis formation in the vicinity of the site of old Fort Ellis in order to determine its lithologic and stratigraphic characteristics and its probable correlation with Upper Jurassic rocks elsewhere in the Western Interior region. The best exposed section was found along the north side of U. S. Highway 10 on the north side of Rocky Creek Canyon about 3.7 miles southeast of the site of Fort Ellis, or 7 miles southeast of Bozeman Court House, in Sec. 19, T. 2 S., R. 7 E., Gallatin County. Just west of this point Highway 10 crosses by bridge both the Northern Pacific Railroad and Rocky Creek. Less well exposed sections may be found (1) about ¼ mile farther east near the top of a mountain and (2) about 3 miles north of Fort Ellis on the north side of Bridger Creek Canyon. As the section near the road along Rock Creek Canyon is the most accessible and best exposed of the three, it is herein designated the type section.

SECTION OF ELLIS FORMATION, 3.7 MILES SOUTHEAST OF FORT ELLIS, IN SEC. 19, T. 2 S., R. 7 E., ON NORTH SIDE OF ROCKY CREEK CANYON, GALLATIN COUNTY, MONTANA

	Feet
MORRISON FORMATION	
25. Basal beds concealed; lower part consists mainly of shale and siltstone containing limestone nodules but includes some ledge-forming sandstone and is characterized by pastel shades of red, green, yellow, and gray; upper part dark gray to purplish gray, shaly to silty, more or less carbonaceous, containing a couple of thin seams of coal, and interbedded with lenticular, fine-grained sandstone	110

[1] Manuscript received, February 10, 1945. Published by permission of the director of the Geological Survey and the officials of the Carter Oil Company.

[2] Geologist, Carter Oil Company, Vernal, Utah.

[3] Geologists, Geological Survey, United States Department of the Interior, Washington, D. C.

[4] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U. S. Geol. Survey Bull. 110* (1893). See Map.

[5] J. P. Iddings and W. H. Weed, "Livingston," *U. S. Geol. Survey Geol. Atlas Folio 1* (1894).

[6] A. C. Peale, "Three Forks," *U. S. Geol. Survey Geol. Atlas Folio 24* (1896).

ELLIS FORMATION

24. Sandstone, thick-bedded, fine-grained, light gray, glauconitic; weathers brown; some surfaces ripple-marked, or marked by wood impressions; some layers contain *Ostrea strigilecula* White, *Eumicrotis curta* (Hall), and rhynchonellid brachiopods 16
23. Sandstone and sandy shale; sandstone as in No. 24, interbedded with dark gray, micaceous shale whose surfaces bear ripple marks and worm-like tracks, and weather bluish gray 7
22. Sandstone, as in unit 24; some layers contain *Ostrea strigilecula* White and rhynchonellids 22
21. Limestone, very sandy, massive, beds 3–4 feet thick, bluish gray, weathering brownish gray; contains much comminuted fossil material, including *Eumicrotis curta* (Hall), *Ostrea strigilecula* White, rhynchonellids, belemnites, *Tancredia? Dosinia?;* some impressions of wood fragments and some worm-like tracks on surfaces 6
20. Sandstone, fine-grained, hard, calcareous, dark gray, weathering light chocolate brown, ripple-marked; weathered surfaces bear small spots of limonite 5½
19. Limestone as in unit 21 and containing same fossils; also contains a few scattered pebbles of yellow quartzite and black, grayish yellow, and greenish chert as much as ½ inch in diameter, but averaging between ⅛ and ¼ inch; some shale partings 7
18. Sandstone, thin-bedded to flaggy (beds ½ to 18 inches thick) fine- to very fine-grained, dark gray, weathering dark brown to brownish gray, slightly glauconitic; sandstone layers separated by dark gray, micaceous shale that weathers bluish gray and occurs in beds as much as 6 inches thick; basal 1½ feet contains a few pebbles of quartzite and chert as in unit 19; surfaces bear worm-like burrows and ripple marks throughout. Conglomeratic layers contain *Ostrea strigilecula* White; upper foot contains *Cardioceras?* sp. 15
17. Shale, chunky, calcareous, medium gray, weathering yellowish gray; a few thin beds of limestone near top; contains *Gryphaea nebrascensis* Meek and Hayden at top and bottom 9½
16. Limestone, in beds 2–3 feet thick, medium bluish gray, weathers buff-tan, a few shale beds as much as 4 inches thick; limestones full of indeterminable, comminuted fossils 7½
15. Limestone, beds 6 inches to 2 feet thick, interbedded with thin beds of shale, medium gray; weathering yellowish gray; contains abundant *Ostrea strigilecula* White 8½
14. Shale, chunky, calcareous, medium gray, weathering light yellowish gray; limestone beds 1–3 inches thick in upper 3 feet; contains *Camptonectes* sp. 16
13. Shale, chunky, calcareous, light gray, weathering buff; includes many thin beds of hard, nodular limestone; contains *Pentacrinus* sp., *Camptonectes pertenuistriatus* Hall and Whitfield, *C.* cf. *C. platessiformis* White, *Arctica?* sp., *Pholadomya kingi* Meek, *P. inaequiplicata* Stanton, *Pleuromya subcompressa* Meek 7½
12. Limestone, hard, cliff-forming, very thick-bedded except upper 16 inches, oölitic, becoming coarsely oölitic at top, light bluish gray, weathering slightly lighter. On upper surface, *Arctica?* cf. *A.? cinnabarensis* (Stanton) 23
11. Limestone, hard, in two beds, very finely oölitic, dark medium gray, weathering bluish gray 6½
10. Shale, silty, chunky; lower part maroon, upper third maroon mottled with light olive-green; upper 2 feet all light olive-green, poorly exposed 37
9. Covered 22
8. Shale and limestone similar to unit 6, but limestone beds are thinner, more brittle, and form only one-third of the bulk of the unit. One fragment of ammonite found loose at top, probably belongs to *Kepplerites*. Fossils from very base include *Gervillea?* sp., *Ostrea strigilecula* White, *Camptonectes pertenuistriatus* Hall and Whitfield, *C. platessiformis* White, *Lima occidentalis* Hall and Whitfield, *Arctica?* cf. *A.? cinnabarensis* (Stanton), *Volsella subimbricata* Meek, *Thracia weedi* Stanton, *Cercomya punctata* Stanton, *Pholadomya kingi* Meek, *Pleuromya subcompressa* (Meek), *Pinna* sp. 29
7. Shale, chunky, calcareous, medium gray, weathering tannish buff 9½
6. Limestone, shaly, and chunky, calcareous shale, medium gray; weathering light bluish gray to tannish buff; shale and limestone alternate in beds about 2 feet thick. Fossils occur throughout but mainly in lower part, and include *Gervillea? montanaensis* Meek, *Gryphaea planoconvexa* Whitfield, *Camptonectes bellistriatus* (Meek) var. *distans* Stanton, *C. platessiformis* White, *Astarte meeki* Stanton, *Lopha* aff. *L. procumbens* (White), *Arctica?* sp., *Trigonia americana* Meek, *T.* cf. *T. montanaensis* Meek, *Homomya gallatinensis* Stanton, *Volsella subimbricata* Meek, *Pinna* sp. 14½
5. Covered, except upper 4 feet, which consists of ripple-marked, calcareous, laminated, medium gray, shaly siltstone that weathers yellowish brown and contains *Tancredia* sp., *Volsella* sp., *Astarte* sp., *Arctica?* sp. 28

TENSLEEP (?) FORMATION

4.	Chert, nodular as in unit 2	5
3.	Sandstone, dense, hard, fine-grained, light gray, thick- to thin-bedded	15
2.	Chert, nodular, dull gray in the mass, apparently laminated. Chert nodules rounded, as much as 6 inches in diameter, prevailing color greenish gray	20
1.	Sandstone, almost quartzitic, grayish white, with minor soft intervals. About	75

Most of the 28 feet of unit 5 probably belongs in the Ellis formation, as judged by a section measured by T. A. Hendricks and H. D. Hadley about 4½ miles northeast of Bozeman and about ½ mile north of Bridger Creek in the NE. ¼ of Sec. 34, T. 1 S., R. 6 E. The lower 20 feet of their measured section apparently corresponds with unit 5 of the afore-described section and from top to bottom is as follows.

	Feet
Shale, calcareous, brown to gray, fossiliferous; several thin lenses of dense, black limestone in upper part	12
Limestone, thin-bedded, almost lithographic, black, fossiliferous	3
Conglomerate of chert, quartzite and sandstone pebbles as much as 2 inches in diameter in matrix of fine- to coarse-grained sandstone. Rests on white sandstone and dolomite of the Tensleep formation	5

The Ellis formation in the vicinity of Fort Ellis may be summarized as follows.

	Feet
Sandstone and sandy limestone, thick-bedded, glauconitic, light gray, weathering brownish gray; many surfaces bear ripple marks and worm-like tracks; contains *Eumicrotis curta* (Hall) and abundant rhynchonellid brachiopods; minor amounts of dark gray micaceous shale present; lower 7 feet contains small pebbles of chert and quartzite	63½
Sandstone in thin beds alternating with considerable dark gray, micaceous shale, that weathers bluish gray; sandstone is dark gray and weathers brownish; surfaces bear ripple marks and worm-like tracks; basal 1½ feet contains a few pebbles of quartzite and chert; a fragmentary cardioceratid ammonite found at top	15
Limestone and chunky, calcareous shale, medium gray; contains fossils identical with those in Yellowstone Park area	49
Limestone, very thick-bedded, hard, oölitic, light to medium gray	29½
Shale, silty, chunky, mostly maroon but mottled with olive-green in upper third	37
Covered (probably mostly maroon shale)	22
Shale and shaly limestone, medium gray, weathering tannish buff; contains many fossils identical with those in Yellowstone Park area	53
Shale and shaly siltstone, gray to brown, interbedded with lenses of dense, black limestone	15
Conglomerate of chert and quartzite in a matrix of sandstone. Probably occurs sporadically	5
	289

Determination of the exact ages of the various units of the foregoing section must await further study, but most probably the section represents at least the Callovian, Divesian, and Argovian stages of the Upper Jurassic and includes equivalents of marine Jurassic strata found elsewhere in the Western Interior region.

GRAPTOLITES FROM WELL CORE, CARTER COUNTY, OKLAHOMA[1]

CHARLES E. DECKER[2] AND MRS. TOM COLEMAN[3]
Norman, Oklahoma

The well core containing graptolites is from the lower part of the Viola limestone from Hargrave well No. 1, NE. ¼, SE. ¼, SE. ¼ of Sec. 36, T. 4 S., R. 2 W., Carter County, Oklahoma. The well is in the southeast flank of the Bayou oil field, and the core is from the bottom of the well at 4,569–4,575 feet. Part of the core was supplied by W. Baxter Boyd, regional geologist for the Continental Oil Company, Ponca City, Oklahoma, and part of it was obtained by Mrs. Tom Coleman from Charles E. Clowe, Throckmorton, Texas. Graptolites from the core are here described, illustrated, and their significance noted. Mrs. Coleman has studied the well cuttings and has found small fragments of graptolites or graptolite-like plant fragments in association with fusulinids at several horizons.

Graptolites in the plate represented by Figures 1–7 are from the core supplied by Boyd, and those in Figures 8–12 are from the part obtained by Mrs. Coleman.

The graptolites all belong to the order Graptoloidea. They include five genera and species, two varieties, a genus with species undetermined, and three siculae.

DESCRIPTION OF SPECIES

Genus DICRANOGRAPTUS Hall 1865

Dicranograptus nicholsoni geniculatus Ruedemann and Decker

Plate 1, Figure 2

The genus *Dicranograptus* has a proximal biserial end which, as it grows distally, divides later into two uniserial branches. It is only a part of one of these uniserial branches that has been preserved here. In the variety *geniculatus*, the two branches spread rather widely and then make a more or less elbow-like bend turning the distal ends of the branches toward one another. In some specimens of this variety the bend is much more marked than that shown near the middle of Figure 2. This geniculate variety occurs in the basal part of the Viola limestone and is still more common in the Stringtown shale in the quarry near Stringtown, Oklahoma.

The length of this fragment of a colony is 18.33 millimeters and the width varies from 0.5 to 0.875 millimeter. Thecae occur 12 in 10 mm., and they overlap about ⅓–½ their length. Apertural margins are curved with the edge of the margins nearly normal to the long axis of the stipe. A few tiny circular apertures and some small narrow cells seem to represent bithecae. The angle of inclination is small, about 15°. If correctly assigned, this fragment places the position of the core in the lower part of the Viola limestone.

[1] Manuscript received, February 22, 1945.

[2] Research professor in paleontology, University of Oklahoma.

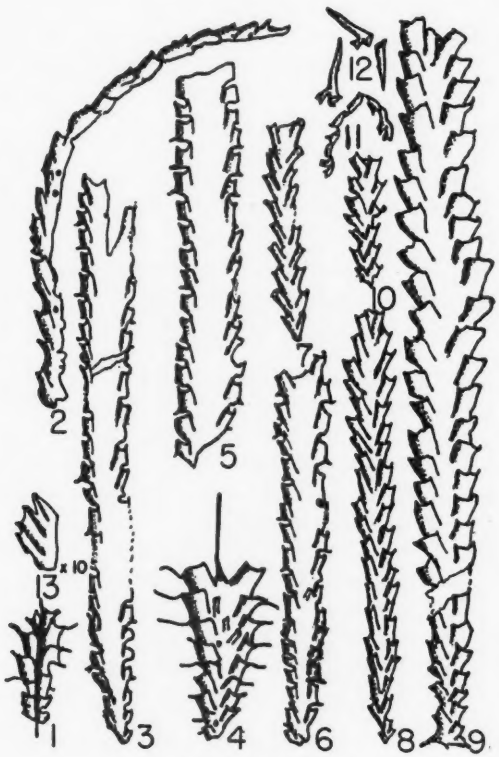
[3] Graduate student in geology, University of Oklahoma.

Genus DIPLOGRAPTUS McCoy 1854

Diplograptus vespertinus Ruedemann

Plate 1, Figures 7, 8, 10

This is one of the smaller species of *Diplograptus*. It is abundant in the lower part of the Viola limestone. The three stipes shown in Figures 7, 8, and 10 vary



EXPLANATION OF PLATE I

(All figures are magnified ×4 except Figure 13 which is ×10, and all figures are from core except Figure 13.)

FIG. 1.—*Lassiograptus eucharis* (Hall).
FIG. 2.—*Dicranograptus nicholsoni geniculatus* Ruedemann and Decker.
FIGS. 3, 5, 6.—*Climacograptus typicalis crassimarginalis* Ruedemann and Decker.
FIG. 4.—*Glossograptus quadrimucronatus spinigerus* Lapworth.
FIGS. 7, 8, 10.—*Diplograptus vespertinus* Ruedemann.
FIG. 9.—*Glossograptus quadrimucronatus* (Hall).
FIG. 11.—*Chaunograptus* sp.
FIG. 12.—Three siculae, two showing start of first thecae.
FIG. 13.—Fragment of graptolite, or graptolite-like fragment of plant on rock in cuttings from well at 235–245 feet.

in length from 5 to 8 to 16.25 mm. and in width from 0.5 to 1.75 mm. The form represented in Figure 7 is narrowed in the central part by compression, especially along the right margin. In Figures 7 and 10 thecae occur 12 in 10 mm. and in Figure 8 they occur 11–13 in 10 mm. Thecae vary in length from 0.75 to 1 mm. and in width from 0.4 to 0.5 mm. Their angle of inclination is 30° – 40°. Thecae overlap $\frac{1}{3}$–$\frac{1}{2}$ their length. As a rule the apertures are concave and their margins are nearly normal to the direction of the stipe.

This species was described in part by Hall[4] (1847) as *Diplograptus pristis* and later by Ruedemann[5] (1908) as *Diplograptus pristis* mut. *vespertinus*, and with it he included *Diplograptus recurrens* which occurs at a much higher horizon in the Viola limestone. *Diplograptus vespertinus* is common in the lower part of the Viola limestone in almost every section where the basal part of the formation crops out. There are very numerous species in the genus *Diplograptus* in the upper Ordovician where they occur in almost world-wide distribution.

Genus Glossograptus Emmons 1856

Glossograptus quadrimucronatus (Hall)

Plate 1, Figure 9

This large specimen has box-like thecae which are characteristic of the genus in certain views. The stipe has a length of 27.5 mm. and a width of 1–3.25 mm. Thecae occur 9–11 in 10 mm. and overlap $\frac{1}{4}$–$\frac{1}{3}$ their length. They are inclined at angles of 20° –30°. Thecae have a length of 0.75–2.5 mm. and a width of 0.5–0.75 mm. Some apertures are slightly concave and their margins are nearly normal to the direction of the stipe. In this view sharp spines do not show, but in some views spines extend laterally from the outer edge of the apertural margin. While this genus has few species, it occurs widespread in North and South America, Europe, Asia, and Australia. This is one of the forms illustrated by Ruedemann[6] which has been preserved in eastern New York in compound colonies with air floats and reproductive sacs. This species is abundant in the lower part of the Viola limestone.

Glossograptus quadrimucronatus spinigerus Lapworth

Plate 1, Figure 4

The variety *spinigerus* illustrated by Elles[7] and Wood as *Orthograptus* is characterized by having lateral spines well developed with exceptionally long

[4] James Hall, *Paleontology of New York*, Volume 1 (1847), Pl. 72, Figs. 1, 1a–b, 1k–l.

[5] Rudolf Ruedemann, "Graptolites of New York. (Higher Beds)." *New York State Mus. Memoir II* (1908), pp. 352–54, text Fig. 296, Pl. 25.

[6] Rudolf Ruedemann, "Development and Growth of Diplograptus McCoy," *14 Ann. Rept. State Geologist of New York* (1894) 1895, pp. 219–49, Pls. 1–5.

[7] Gertrude Elles and Ethel M. R. Wood (Mrs. Shakespear), "Monograph of British Graptolites," *Paleontographical Society of London* (1901–1918), Pl. 28, Figs. 2a–d.

ones on the tenth thecal pair. The specimen in Figure 4 represents only the proximal end of the stipe below the tenth thecae and so does not exhibit the long spines. However, this proximal part is identical with numerous specimens of the variety which occur in the basal part of the Viola limestone, especially in the outcrops along U. S. Highway 77. The two circular openings and three small cells probably represent bithecae to house stinging cells.

Genus CLIMACOGRAPTUS Hall, 1865

Climacograptus typicalis crassimarginalis Ruedemann[8] and Decker

Plate 1, Figures 3, 5, 6

Thecae of the genus *Climacograptus* are characterized by a double bend. At first they are directed outward and upward and then by an abrupt bend they are turned in a direction nearly parallel with the direction of the stipe. The diagnostic feature of the variety *crassimarginalis* is the presence of sharp marginal spines at the outer bend of the thecae at the upper edge of the apertural notch. The three specimens representing this variety in Figures 3, 5, and 6 have lengths of 113, 115, and 141 mm. and widths varying from 1 to 2.5 mm. Thecae occur 11–14 in 10 mm. Apertures are concave and apertural indentations are equal to about $\frac{1}{6}$ the width of the stipe.

Genus LASSIOGRAPTUS Lapworth, 1873

Lassiograptus eucharis (Hall)

Plate 1, Figure 1

The small stipe in Figure 1 is best preserved of a number that occur close together on the core. These may represent parts of a broken compound colony. They occur in great abundance in the lower part of the Viola limestone and there they commonly show propinquity and orientation as though they belong to compound colonies.

The small stipe is 5 mm. long and varies in width from 1 to 1.5 mm. Individual thecae approach the shape of those in *Glossograptus* and they exhibit similar apertural spines. Thecae occur 14–16 in 10 mm. A central thread-like nema is present. Abundant and widespread in the lower part of the Viola limestone, commonly with thecal wall exfoliated with only thread-like meshes remaining, it occurs in the Utica shale and adjacent formations in New York.

Genus CHAUNOGRAPTUS Hall, 1881

Chaunograptus sp.

Plate 1, Figure 11

The small part of a colony shown in Figure 11 is the first to be discovered in the Viola limestone. The tiny thecae show little if any overlap and they occur

[8] Rudolf Ruedemann and Charles E. Decker, "The Graptolites of the Viola Limestone," *Jour. Paleon.* Vol. 8 (1934), p. 318, Pl. 42, Figs. 9, 10, 10a.

20 in the space of 10 mm. It has little value except to indicate its presence with the typical Viola graptolites. The genus occurs with little change from Upper Cambrian into the Devonian. These forms are now commonly classed with the hydrozoans.

SICULAE

Plate 1, Figure 12

The three siculae illustrated are only a few of a large number scattered over the surface in the core. They represent the initial bodies from which all colonies of graptolites develop. Two of them show the first theca starting from the sicular foramen. Siculae are abundant in the lower part of the Viola limestone both at the north and south ends of the Criner Hills and at some localities in the Arbuckle Mountains.

Thus we find in this core four species, two varieties, and siculae characteristic of the lower part of the Viola limestone. The small thickness of 30 feet of Viola in this well doubtless represents only a small fraction of its original thickness. The Viola trebles in thickness from the east to the west end of the Arbuckle Mountains where it is 929 feet thick, and in the middle of the Criner Hills it has a thickness of 908 feet. This would seem to indicate erosion of nearly 900 feet from the top of the Viola. So it would be necessary to use the base instead of the top of the Viola to work out structural relations.

FRAGMENT

Plate 1, Figure 13, ×10

In addition to the graptolites in the core, fragments occur in the cuttings at higher levels. Mrs. Coleman studied the cutting and found fragments of graptolites or graptolite-like plant fragments in three zones above the one from which the core was taken. These zones are high in what is considered the Pennsylvanian section of the well: zone 1 (235–245), zone 2 (1,035–1,045), zone 3 (1,285–1,295 feet), while the core came from 4,569–4,575 feet, the bottom of the well. If the fragments are plants, no explanation is necessary. If the fragments are graptolites, it seems necessary to postulate that one or more of the graptolite zones in the Henryhouse, Sylvan, or Viola were high enough in the vicinity of the western Arbuckle Mountains or northern Criner Hills to supply the graptolite fragments to these upper zones in the well. Fragments from the other two zones are smaller than the one shown in Figure 13.

By means of the graptolites in this core the horizon may be correlated closely with the 6,398–6,402-foot zone in the Phillips Petroleum Company's Goodin No. 1 in eastern Cleveland County, Oklahoma, and with the 7,728-foot zone in the Carter Oil Company's well, Sec. 35, T. 18 N., R. 1 E., north of the Black Hills in South Dakota.

CALHOUN FIELD, COLUMBIA COUNTY, ARKANSAS[1]

F. B. STEIN[2]
Tyler, Texas

The Calhoun field is located in central Columbia County, Arkansas, approximately 6 miles southeast of the town of Magnolia, 3 miles northwest of the West Atlanta field, and 5 miles northeast of the Macedonia field.

Exploration in the area began early in 1938, when the Tide Water Associated Oil Company and the Seaboard Oil Company, operating jointly, worked the area with reflection seismograph, which showed the presence of an anomaly in T. 18 S., R. 20 W. In the course of getting the picture worked out, the two companies reworked the area in the spring of 1939, and again in the summer of 1942. In August, 1943, after the discovery of the West Atlanta field, the two companies assembled a block of leases which was to be tested immediately.

On October 13, 1943, the Tide Water Associated Oil Company and the Seaboard Oil Company began drilling L. H. Pearce No. 1, the discovery well, at a location in the center of the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 10, T. 18 S., R. 20 W. The well was bottomed at 8,290 feet in the Reynolds oölitic zone of the Smackover limestone, and $5\frac{1}{2}$-inch casing was cemented to bottom. On a production test through perforations at 8,282–8,287 feet, the well flowed 84 barrels of 51.5° A.P.I. oil in 24 hours through a $\frac{1}{8}$-inch choke with a gas-oil ratio of 5,900 to 1. The well was then drilled to the present total depth of 8,298 feet and completed from open hole at 8,290–8,298 feet in the Reynolds oölitic zone, producing 34 barrels of 50° A.P.I. oil in 24 hours through a 6/64-inch choke with a gas-oil ratio of 5000 to 1, on February 22, 1944.

To date there are three completed wells and one dry hole which has defined the field on the south. From present information, the structure of the field appears to be an anticlinal ridge bearing approximately east and west.

The field is being developed on a 40-acre spacing program and, with the exception of a few leases, is controlled by the Tide Water Associated Oil Company and the Seaboard Oil Company, operating jointly.

[1] Manuscript received, March 5, 1945.

[2] Tide Water Associated Oil Company.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 4 (APRIL, 1945), PP. 460-466

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

THE MIGRATION AND ACCUMULATION OF PETROLEUM AND NATURAL GAS, BY F. M. VAN TUYL, BEN H. PARKER, AND W. W. SKEETERS

REVIEW BY W. P. HAYNES[1]
New York, N. Y.

*"The Migration and Accumulation of Petroleum and Natural Gas," by F. M. Van Tuyl, Ben H. Parker, and W. W. Skeeters. *Colorado School of Mines Quart.*, Vol. 40, No. 1 (Golden, January, 1945). 111 pp. including Table of Contents, Abstract, Introduction, and Bibliography. Price, $1.50.

The authors, members of the department of geology, Colorado School of Mines, Golden, Colorado, have done a very commendable piece of work in digesting and compiling the material collected during the years 1939 to 1943 at the conferences on "Migration and Accumulation of Oil," sponsored by the research committee, held in connection with the annual meetings of the A.A.P.G. This material was augmented by correspondence with many petroleum geologists and their comments as well as extracts from the literature are included in this report.

The authors state in the introduction that

> this review of the present status of the problem of the migration and accumulation of petroleum and natural gas makes no claim for the solution of this baffling question. It represents rather an attempt to coordinate and analyze the known data and to weigh the current theories. Suggestions are also offered for further investigations with the hope that a broad, well coordinated attack may be formulated.

They note that

> the problem of migration and accumulation of oil and natural gas is intimately related to the question of time of origin of these hydrocarbons . . . the story of accumulation cannot be fully told until more authentic information is available regarding the time, with reference to the age of associated strata, of the generation of liquid and gaseous hydrocarbons.

Three major topics are covered.

1. EXTENT AND CHARACTER OF MIGRATION, with statements of evidence from geologists supporting a local origin and also supporting a substantial migration (pp. 8–28).
2. ANALYSIS OF THE PROBLEM OF MIGRATION AND ACCUMULATION, which includes a rather complete topical outline with sub-headings of (a) Possible Types of Concentration; (b) Possible Physical Form of Hydrocarbons or Mother Substance during Migration and Accumulation; (c) Nature and Mode of Migration and Location of Accumulations; and (d) Time of Origin and Accumulation (pp. 28–56).
3. MODE OF MIGRATION AND ACCUMULATION, with a summary of the various theories of migration and accumulation, supported by numerous citations (pp. 56–103).

Conclusions cover four pages (103–06) and include the following statements which seem to be particularly significant.

> We know little regarding the character of oil during the early stages of its evolution.
> Oil has not been observed in process of migration, except under experimental conditions, . . . the time element and the effect of many variable factors, which cannot all be taken into consideration in thelaboratory, render definite conclusions of doubtful value.

[1] Standard Oil Company (New Jersey), 30 Rockefeller Plaza.

It is obvious that, unless the hydrocarbons are generated early in the history of the source sediments, migration from shales to reservoirs by capillary flow must be of little or no importance, for in compacted shales the openings are of subcapillary size.

In view of the foregoing situation and the existence of innumerable other conditioning factors any attempt to evaluate the various theories of migration and accumulation seems to be unjustified now. The evidence suggests that buoyancy, hydraulic flow, screening, compaction (both sedimentary and tectonic) capillarity, and pressures generated within the migrating fluids by expanding gas and by cementation may have all had roles of more or less importance in the formation of existing concentrations of oil and gas.

Large-scale paleogeologic and paleogeographic studies must be undertaken in order to increase our understanding of the time of origin and accumulation of oil and the nature of source beds and their relation to the reservoirs.

The practical solution of the problem, however, demands both a regional and local treatment. If certain geologists, physicists and production engineers in each petroliferus province in the United States could be prevailed upon to work in cooperation on this problem under a regional committee, it does not seem unreasonable to hope that, within a comparatively short time, a workable hypothesis could be developed for each area.

A bibliography of references is included on pages 106–11.

The research committee of the A.A.P.G. hopes that all *Bulletin* readers who are interested in this project will secure a copy of this stimulating report, and will also lend their active coöperation and support to any further studies as suggested therein.

AN INTRODUCTORY DISCUSSION OF THE RESERVOIR PERFORMANCE OF LIMESTONE FORMATIONS, BY A. C. BULNES AND R. U. FITTING, JR.

REVIEW BY JOHN M. HILLS[1]
Midland, Texas

"An Introductory Discussion of the Reservoir Performance of Limestone Formations," by A. C. Bulnes and R. U. Fitting, Jr. *Amer. Inst. Min. Met. Eng. Tech. Pub. 1791*, Class G, Petroleum Division, No. 226 (1944).

The paper by Bulnes and Fitting is an important contribution, not only to engineering but also to geological literature. The main concern of the authors is, of course, to point out the characteristics of limestones which affect their performance as reservoirs for oil and gas, and to lay the foundation for a precise and quantitative measurement of these characters. This in itself is an undertaking of considerable magnitude, for, as the authors observe, "the literature of production research published during the past fifteen years reveals a startling absence of theoretical and experimental investigations directed specifically toward explaining and predicting the performance of limestone reservoirs." This same lack has been noted by most petroleum geologists working in areas of limestone production. This is, in itself, unfortunate from a scientific viewpoint. Moreover, when it also is accompanied by well-completion methods and production practices based on ill founded analogies with sandstone reservoirs, it becomes economically tragic.

There are many characteristics of limestones, their crystalline structure, irregularity of their internal void systems, susceptibility to fracture, and other qualities which differentiate them from sandstones. The geologist whose mental attitude toward rocks is conditioned by a familiarity with their origin and history takes all these characteristics for granted and sees no reason why the limestones and sandstones should behave alike when acting as oil and gas reservoirs. He needs no proof of the obvious.

The engineer, however, approaching a study of oil and gas reservoirs by the method

[1] Consulting geologist, Box 418. Review received, March 6, 1945.

of quantitative measurements and mathematical interpretation, must present evidence to support the separation of limestone reservoirs from the reservoirs of the classical sandstone type. The authors very ably present such evidence. In so doing they also present avenues of quantitative approach to geological problems concerning limestones which geologists may pursue with much profit to themselves and their profession.

First, the authors consider the internal void system, or, as we more commonly and loosely say, the porosity of sandstones and limestones. They point out the dispersion and interconnection of most void systems. Cementation reduces the size of this system but does not fundamentally alter its nature. Then they go on to say that "if a limestone has nowhere suffered fracture or any evolutionary process by which its internal void volume has been increased at the expense of the original sedimentary units, there is no reason to expect any fundamental difference between its void system and that of a sandstone."

This is possibly a true statement in the case of lime sands, coquinas, and oölites. Many limestones, however, by the close of the period of diagenesis are well consolidated and form masses of interlocking crystals with little porosity. No matter how small this porosity may be and how low the permeability of the rock, it is true that it must be classified geometrically as intergranular. Nevertheless, the development of porosity and permeability in amounts sufficient to be of practical importance in production of oil and gas seems to be a result of solution and recrystallization taking place shortly after lithification. Porosity resulting from this process will probably be similar to that of sandstones while later solution, especially near-surface or subaerial, results in development of cavernous porosity which differs radically from the void system of sandstones. Further geological research is needed to establish the relative age of the various types of porosities in limestones.

The authors conclude that there are three types of void systems, two of which commonly occur in sedimentary rocks. The first of these is called intergranular. This consists of interconnected voids forming the interstices between granules making up the rock. Sandstone porosity is a typical example. Other examples are the voids in granular dolomites in unconsolidated oölites, and the voids in leached oölites, if interconnected.

Foramenular void systems consist of openings through or in an otherwise continuous solid. The authors give as examples a mass of glass containing bubbles, and a pipe. The geologist might add vesicular lava, leached unconnected oölites, and pinpoint porosity in limestone to this list.

Intermediate void systems are those which have cavities in addition to intergranular openings. Most limestones show this type of void system, due to secondary solution along definite channels. There are all degrees of intermediate porosity, from the nearly entirely intergranular dolomites to the cavernous limestones of the reefs and the faulted nearly impervious limestones which are almost completely foramenular. An interesting piece of research would be correlation of the type of porosity with the processes the rock has undergone.

The next section of the paper points out the great variability in porosity-permeability relationships in limestone as compared with sandstones. This point is illustrated by a series of core analyses. These show (if proof is necessary) that analyses of single limestone cores have little meaning when applied to a whole reservoir. Since the highly permeable and cavernous sections of the limestone reservoir beds are rarely recovered in coring, a single core is even less representative than the analyses show.

However, for intergranular media, for example, sandstones and a few limestones, porosity and permeability are functions of each other since they are determined by nearly the same variables. This gives some mathematical basis to the rough empirical observation that porosity and permeability show a close relationship to each other in most formations.

The authors plotted about 2,200 sandstone core analyses, largely from published sources, showing porosity against permeability. The points occupy a very definite area

on the plot with most points ranging from 30 to 10 per cent porosity and from 500 to 10 millidarcys permeability. There is great thinning of points below 10 per cent porosity and 10 millidarcys permeability. The authors suggest that this is due to sparse occurrence in nature of sandstone of this character. The geologist can see no reason for there not being a continuous gradation from the pure sandstones through the shaly sandstones and sandy shales to the impermeable shales. He suggests that the apparent discontinuity is due to the fact that the shaly beds are obviously not pay formations and are thus less often cored and seldom analyzed.

The porosity and permeability of approximately 1,200 dolomitic limestone cores were plotted. These showed somewhat the same distribution as the sandstone analyses, but tended to be lower in permeability and higher in porosity than the sandstone samples. All these samples were intergranular in physical appearance. However, their high porosity and low permeability indicated that solution and possible fracturing had taken place. To the geologist, this seems to be strong evidence that, while there may be primary porosity in limestones, it has been affected strongly by secondary solution along lines predetermined by sedimentary processes.

Possibly the most significant thing about the plotting of limestone porosity and permeability is the fact that plots of many analyses fall below the lower boundary of the intergranular area showing much less porosity than sandstones of the same permeability. Also the plots of half a dozen analyses from cores showing obvious cavernous character fell far to the right of the rest of the data and entirely out of the intergranular area. Possibly the reason more such points are not shown is that limestone with cavernous porosity, which from evidence of cuttings and drilling time is fairly common in limestone reservoirs, is very seldom recovered in coring. This distribution of points indicates that limestones are very different in their void systems from sandstones. Among other things they tend to show lower porosities for a given permeability than sandstones.

In this connection, the reviewer would like to remark that the assembling of the numerous core data presented by the authors helps to make this paper very important. Core recovery in limestone "pay" is much lower than in sandstone and ordinarily several wells must be cored to obtain one core record complete enough to be significant. Many wells must be cored to obtain sufficient analyses upon which to base even tentative conclusions.

In the conclusion to the section on porosity and permeability the authors point out that it is possible to correlate cutting examinations with core analyses to get some idea as to porosity and permeability from cutting examination alone. It also occurs to the geologist that examination of fragments of analyzed cores would throw much light on the origin of limestone porosity. In the next section of the paper the authors present a number of permeability profiles of sandstone and limestone wells. They point out that sandstone "pays" generally show thick beds of highly permeable rock with thin streaks of low permeability. These streaks are due to shaly beds and can be correlated from well to well. Limestone "pays," however, consist of thick bodies of rock with low permeability (less than 0.1 millidarcy) with thin streaks of more highly permeable rock. These streaks do not necessarily follow the bedding, and apparently are the results of secondary solution, or possibly fracturing. This renders prediction of productivity of limestones, even in proved fields, difficult.

These permeable streaks seem to be the channels which are affected by acid treatment. They also act as conduits to carry the oil from the "pay" of low permeability into the well bore. One of the most important conclusions to be drawn from this theory of limestone reservoirs is that secondary recovery in such reservoirs must be very cautiously approached, since the permeable streaks in the formation might concentrate the flow of fluids and result in the by-passing of considerable quantities of oil in the beds of low permeability. Repressuring also may reduce the pressure gradient between the low-per-

meability rock and the channels of high permeability and thus decrease the flow into the well bore and decrease recovery.

The authors then investigated the lower effective limits of permeability in sandstones and limestones. Through production history as well as bottom-hole pressure build-ups, residual water saturation, and relative permeability, they came to the conclusion that limestone of less than 0.1 millidarcy permeability and porosity as low as 4 per cent may produce important quantities of oil. Furthermore, the depletion oil saturation of limestone may be as low as 25 per cent. This indicates that ordinary recovery methods may result in recovering a much larger proportion of the oil in limestone formations than had previously been thought possible from studies made on sandstone cores. Such recovery may run as high as 75 per cent but probably will be very slow.

Two other conclusions of the authors deserve the attention of geologists and executives. One is that the material-balance method of calculating recoveries fails to be entirely satisfactory in limestone reservoirs because of the difficulty in determining true equilibrium pressure. The second, and more important conclusion, is that complete study of the engineering and geological data and their coördination are necessary to an understanding of the performance of limestone reservoirs. The geologist might add that this coördination between physical and geological data is necessary in the understanding of the performance of any reservoir. Certainly no study of any reservoir for the purpose of secondary recovery or repressuring should be undertaken without a coördinated geological study. The geologist making the study certainly should be familiar with engineering papers such as this one.

RECENT PUBLICATIONS

ALABAMA

*"Oil in Alabama," by Stewart Lloyd. *World Petroleum*, Vol. 16, No. 2 (New York, February, 1945), pp. 52–53, photographs.

ARIZONA

*"Oil and Gas Prospects in Arizona," by P. H. Lund. *Oil Weekly*, Vol. 117, No. 2 (Houston, March 12, 1945), pp. 54–56; 1 sketch map.

ARIZONA AND UTAH

*"Geomorphology and Structure of the East Kaibab Monocline, Arizona and Utah," by Donald L. Babenroth and Arthur N. Strahler. *Bull. Geol. Soc. America*, Vol. 56, No. 2 (New York, February, 1945), pp. 107–50; 9 pls., 16 figs.

*"Geology of the Uinkaret Plateau, Northern Arizona," by E. Donaldson Koons. *Ibid.*, pp. 151–80; 4 pls., 12 figs.

CALIFORNIA

"Geology and Oil Possibilities of Puente and San Jose Hills, California," by A. O. Woodford, J. S. Shelton, and T. G. Moran. *U. S. Geol. Survey Prelim. Map 23*, Oil and Gas Inves. Ser. (February 10, 1945). Sheet 44×64 inches. Scale: 1 inch equals 1 mile. Includes 16 structure sections on a scale of 1 inch equals 2,000 feet and 1 section on a scale of 1 inch equals 500 feet; descriptive text; and list of wells. For sale by Director, U. S. Geol. Survey, Washington 25, D. C., and 533 U. S. Post Office and Courthouse Building, Los Angeles, California.

"Geology of Santa Rosa Hills, Eastern Purisima Hills District, Santa Barbara County, California," by W. P. Woodring, J. S. Loofbourow, Jr., and M. N. Bramlette. *U. S. Geol. Survey Prelim. Map. 26*, Oil and Gas Inves. Ser. (February 13, 1945). Generalized geologic map on sheet 39×43 inches. Scale, 1 inch equals 4,000 feet. Includes 4 structure sections

on same scale, 11 graphic sections on vertical scale of 1 inch equals 200 feet, brief text, and table. For sale by Director, U. S. Geol. Survey, Washington 25, D. C., and Room 533, U. S. Post Office and Courthouse Building, Los Angeles, California. Price, $0.35.

"Geology and Oil Possibilities of the Salinas Valley, California," by M. N. Bramlette and S. N. Daviess. *U. S. Geol. Survey Prelim. Map 24*, Oil and Gas Inves. Ser. (February 13, 1945). Sheet 40×53 inches. Geologic map on scale of 1:125,000. Includes a diagram showing variations in thickness, 5 structure sections, a list of 76 wells, and brief text. For sale by Director, U. S. Geol. Survey, Washington 25, D. C., and Room 533, U. S. Post Office and Courthouse Building, Los Angeles, California. Price $0.35.

*"Geology of the Jamesburg Quadrangle, Monterey County, California," by William Morris Fiedler. *California Jour. Mines and Geol.*, Vol. 40, No. 2 (San Francisco, April, 1944), pp. 178–250; 32 figs, 2 pls.

"Geology of the Bituminous Sandstone Deposits near Santa Cruz, Santa Cruz County, California," by Ben M. Page, M. Dean Williams, Eiler L. Hendrickson, Clifford N. Holmes, and William J. Mapel. *U. S. Geol. Survey Prelim. Map 27*, Oil and Gas Inves. Ser. (March 15, 1945). Geologic and topographic maps on scale of 1 inch equals 300 feet; 3 cross sections on same scale; 2 index maps; stratigraphic diagram; and descriptive text. One sheet, 34×54 inches. For sale by Director of the Geological Survey, Washington 25, D. C., and 533, U. S. Post Office and Courthouse Building, Los Angeles, California. Price $0.60.

COLORADO PLATEAU

"Correlation of Basal Permian and Older Rocks in Southwestern Colorado, Northwestern New Mexico, Northeastern Arizona, and Southeastern Utah," by N. W. Bass. *U. S. Geol. Survey Prelim. Chart 7*, Oil and Gas Inves. Ser. (February 12, 1945). Sheet 38×46 inches. Includes 13 graphic columnar sections on vertical scale of 1 inch equals 200 feet and index map on scale of 1 inch equals 16 miles. Accompanied by mimeographed text and table. For sale by Director, U. S. Geol. Survey, Washington 25, D. C.; Room 234, Federal Building, Tulsa, Oklahoma, Room 314, Boston Building, 828 17th Street, Denver, Colorado. Price, $0.40.

CUBA

*"Outline of the Geology of Cuba," by R. H. Palmer. *Jour. Geol.*, Vol. 53, No. 1 (Chicago, January, 1945), pp. 1–34; 6 figs., 1 table.

ENGLAND

"The Carboniferous Rocks of the Swinden Anticline, Yorkshire. With a Redefinition of the Boundary between Tournaisian Visean in England," by R. G. S. Hudson and H. V. Dunnington. *Proc. Geologists' Association*, Vol. 55, Pt. 4 (London, January 26, 1945), pp. 195–215; 3 figs., 2 pls.

FLORIDA

*"Florida Geology and Petroleum," by Herman Gunter. *World Petroleum*, Vol. 16, No. 2 (New York, February, 1945), pp. 56–57, photographs.

GENERAL

"The Divining Rod, a History of Water Witching, with a Bibliography," by A. J. Ellis. *U. S. Geol. Survey Water-Supply Paper 416* (1938). Reprinted (1945). 59 pp., 4 figs. Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price $0.15.

"The Application of Tilt to a Fold," by G. D. Hudson. *Proc. Geologists' Association*, Vol. 55, Pt. 4 (London, January 26, 1945), pp. 216–21; 3 figs.

"Note on the Origin of Island Arcs," by A. J. Bull. *Ibid.*, pp. 222–26; 1 fig.

*"Oil for the Future," by William B. Heroy. *Econ Geol.*, Vol. 39, No. 8 (Urbana, Illinois, December, 1944), pp. 593–99.

"The Army's Pet Prophets," by Martin Sommers. *Saturday Evening Post*, Vol. 217, No. 39 (Philadelphia, March 24, 1945), pp. 18–19 and 97–98; 4 photographs. Dramatized praise for that part of the geological profession helping to win the war by predicting airfield sites, landing beaches, and other terrane on the battle fronts. " . . . The military-geology unit of the Geological Survey is the biggest bargain the Army has got in wartime."

GEORGIA

*"Prospecting for Oil and Gas in Georgia," by Garland Peyton. *World Petroleum*, Vol. 16, No. 2 (New York, February, 1945), pp. 54–56, photographs.

INDIA

*"The Age of the Punjab Salt in the Light of Recent Evidence," by B. Sahni. *Proc. Natl. Acad. Sci. India*, Vol. 14, Nos. 1–2 (Lucknow, September, 1944), pp. 49–66; 14 figs.

IOWA

*"The Stratigraphy of the Independence Shale of Iowa," by Merrill A. Stainbrook. *Amer. Journ. Sci.*, Vol. 243, No. 3 (New Haven, Connecticut, March, 1945), pp. 138–58; 2 figs.

MICHIGAN

"Sections and Maps of Lower Ordovician and Cambrian Rocks in the Michigan Basin, Michigan and Adjoining Areas," by George V. Cohee. *U. S. Geol. Survey Prelim. Chart 9*, Oil and Gas Inves. Ser. (March 15, 1945). Includes 3 series of columnar sections on a vertical scale of 1 inch equals 200 feet; 5 small maps on a scale of 1 inch equals 80 miles; and a brief text on stratigraphy, structure, and oil and gas possibilities. One sheet, 35×54 inches. For sale by Director of the Geological Survey, Washington 25, D. C., and the Michigan Geological Survey Division, Lansing 13, Michigan. Price, $0.40.

MISSISSIPPI

*"Mississippi Oil Resources," by William Clifford Morse. *World Petroleum*, Vol. 16, No. 2 (New York, February, 1945), pp. 53–45, photographs.

OREGON

*"Some Revisions of the Late Cenozoic Stratigraphy of the Southern Oregon Coast," Ewart M. Baldwin. *Jour. Geol.*, Vol. 53, No. 1 (Chicago, January, 1945), pp. 35–46; 7 figs., 3 tables.

TEXAS

"Correlation of Lower Cretaceous Formations as Revealed by Deep Wells in East and South Texas," by Ralph W. Imlay. *U. S. Geol. Survey Prelim. Chart 8*, Oil and Gas Inves. Ser. (February 19, 1945). Sheet 35×54 inches. Seven columnar sections on vertical scale of 1 inch equals 400 feet. Index map and correlation table. For sale by Director, U. S. Geol. Survey, Washington 25, D. C., and Room 234, Federal Building, Tulsa, Oklahoma. Price, $0.50.

WASHINGTON

"Megafaunal Zones of the Oligocene of Northwestern Washington," by J. Wyatt Durham. *Bull. Univ. California Dept. Geol. Sci.*, Vol. 27, No. 5. 211 pp., illus. Paper cover. Price, $1.50.

WEST VIRGINIA

*"Permeability, Porosity, Oil, and Water Content of Natural Gas Reservoirs, Kanawha-Jackson and Campbells Creek Oriskany Fields," by A. J. W. Headlee and J. S. Joseph. *West Virginia Geol. Survey Bull. 8* (Morgantown, 1945). 17 pp., 4 figs.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 4 (APRIL, 1945), PP. 467-470. 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Dolan Hoye Eargle, University, Ala.
Hugh D. Miser, Louis C. Conant, Watson H. Monroe
Craig Ferris, Tulsa, Okla.
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Paul Marvin Jameson, Tulsa, Okla.
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Frank August Schultz, Dallas, Tex.
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Allan M. Short, St. Louis, Mo.
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Joe John Waidhofer, Midland, Tex.
Thomas K. Bowles, John T. Isberg, Stanley Carlson

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Elizabeth Anne Elliott, Midland, Tex.
R. W. Harris, M. E. Upson, W. J. Hilseweck
Peter Warren Gester, Caracas, Venezuela, S. A.
G. C. Gester, W. S. W. Kew, W. A. Findlay

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A. N. Murray, H. T. Morley, Jerry E. Upp
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Philip Elmer LaMoreaux, University, Ala.
V. T. Stringfield, Watson H. Monroe, Lyman Toulmin, Jr.
Charles McClelland Lind, Houston, Tex.
H. J. McLellan, Olin G. Bell, P. H. O'Bannon
Gladys Minette Peyser, Los Angeles, Calif.
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Holly Elsie Smith, Midland, Tex.
Caroline E. Heminway, Maria Spencer, Thomas W. Koch
William Russell Sype, Tulsa, Okla.
George V. Dunn, Garvin L. Taylor, R. Clare Coffin
Lloyd Bradish Underwood, Ann Arbor, Mich.
George V. Cohee, Kenneth K. Landes, Rex P. Grant
Peter Gerald Woods, Jr., Bakersfield, Calif.
Arthur S. Huey, Arne Junger, Alfred W. Vitt

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Lynn K. Lee, L. J. Fulton, Darsie A. Green
Joe Harold Edgar Ward, San Antonio, Tex.
R. D. Mebane, H. E. Menger, W. W. Hammond

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WILLIAM EDWIN WALLACE

WILLIAM EDWIN WALLACE—RECIPIENT OF PRESIDENT'S AWARD[1]

A. RODGER DENISON[2]
Tulsa, Oklahoma

The President's Award for 1944 was presented with appropriate ceremony on the evening of March 27 to William Edwin Wallace, Jr., for his article, "Structure of South Louisiana Deep-Seated Domes," published in the September, 1944, *Bulletin* of the Association.

This is the first presentation of this award which was instituted in 1944. The award consists of $100 in cash plus a citation. The purpose of this award is to honor and reward the younger authors who publish in the *Bulletin*. To be eligible an author must not have passed his fortieth birthday on the first day of the year in which his article appears. The selection of the candidate for the award is by action of the Medal Award committee who, under the rules of the award, choose the article which makes the most significant contribu-

[1] Manuscript received, March 21, 1945.
[2] Chairman, medal award committee.

tion. This selection is submitted to the executive committee and on their approval the author is declared the recipient of the award.

Wallace is a native of Shreveport, Louisiana, having been born there on June 11, 1911, and is at present working for the Sohio Petroleum Company in Shreveport, being on leave from his position as assistant professor of geology at Centenary College, Shreveport. His public and high-school education was in Shreveport which was followed by 2 years at the New Mexico Military Institute. He then studied 2 years at the University of Oklahoma, receiving a Bachelor of Science degree in geology in 1931. Returning to his native state he did graduate work for a year at Louisiana State University, receiving a Master of Science degree in 1932. From 1933 through 1936 he was employed by the Standard Oil Company of New Jersey as paleontologist at Caripito and Maracaibo, Venezuela.

He was appointed assistant professor of geology at Centenary College in 1938, teaching continuously until 1942, when he took a leave of absence to return to Louisiana State University for further graduate work. He received the degree of Doctor of Philosophy in 1943, his dissertation being a "Study of South Louisiana Deep-Seated Domes." The article for which the award is made is a condensation of this doctor's thesis.

In addition to his connection with the A.A.P.G., Wallace is also a member of the American Association of College Professors and the Geological and Mining Societies of American Universities. During his college studies he was elected to Sigma Gamma Epsilon, Phi Kappa Phi, and Sigma Xi. In addition to the article for which he was given the award he is the author (with H. V. Howe) of "Foraminifera of the Jackson Eocene at Danville Landing, Louisiana," Louisiana Department Conservation Geological Bulletin 2 (1932).

DEFINITIONS OF GEOLOGY[1]

IRA H. CRAM[2]
Chicago, Illinois

In response to the request of the National Roster of Scientific and Specialized Personnel the following definitions have been prepared with the kind assistance of Frederic H. Lahee, Harold W. Hoots, A. Rodger Denison, and C. E. Dobbin.

Petroleum Geology is geology applied in the exploration for and exploitation of petroleum and natural gas deposits.

Field or Surface Geology is the study of exposed rocks and soils with particular reference to the geologic age, distribution, character, sequence, correlation, fossil content, attitude, altitude, and thickness of the rock layers. After recording these stratigraphic and structural data on maps and sections, inferences are drawn as to the stratigraphy and structure of the rock formations below the area investigated, and further inferences based largely upon experience are drawn as to the petroleum and natural gas possibilities. A petroleum geologist who makes these examinations and interpretations is called a surface or field geologist.

Subsurface Geology is the study of unexposed rocks with particular reference to the geologic age, distribution, character, sequence, correlation, fossil content, attitude, altitude, and thickness of the underground or subsurface rock layers. Data for this study are secured through the drilling of wells (including core holes) and through geophysical investigations. By studying logs, cuttings, and cores from wells, physical measurements made inside the well bores, and data furnished by geophysical surveys, information on the stratigraphy and structure of the underground rock formations is obtained, which information finds wide application in both exploration and exploitation. A petroleum geologist who makes these studies and constructs maps and sections to illustrate his interpretations is called a subsurface geologist.

[1] Manuscript received, March 22, 1945.
[2] Executive committee of the Association.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 4 (APRIL, 1945), PP. 471-476

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Association of American State Geologists recently held its thirty-ninth annual meeting, in the offices of the United States Geological Survey, Washington, D. C. Twenty-five of the 43 State geological surveys were represented. The members of the Association heard addresses by Director WILLIAM E. WRATHER of the Geological Survey, and Director R. R. SAYERS of the Bureau of Mines. Director Wrather discussed new mapping techniques developed during the war, especially the use of aerial photographs to speed up the making of maps. By use of modern machinery, it is possible to produce from aerial photographs the highly accurate maps which are essential in the study of national resources as well as for the national security. Director Sayers discussed the exploration of mineral deposits and the development of new methods of treating ores. ROBERT H. DOTT, State geologist of Oklahoma was elected president of the Association for the coming year. EDWARD L. TROXELL, State geologist of Connecticut, was selected as the vice-president, and MEREDITH JOHNSON, State geologist of New Jersey, is the new secretary.

H. G. SCHENCK of Stanford University, has recently been promoted from Major to Lieutenant Colonel in the Army. He has an administrative post at military headquarters somewhere in New Guinea.

C. T. JONES has returned to his former position of senior geologist with Stanolind Oil and Gas Company, Tulsa, Oklahoma, after 4 years active duty with Corps of Engineers, United States Army. He was overseas almost 3 years, seeing service as a Lieutenant Colonel on Ascension Island, in Africa, in the United Kingdom, and on the Continent.

EDWARD C. DOELL, formerly with the Standard Oil Company of California, San Francisco, is with the Richmond Exploration Company, Caracas, Venezuela.

LANCASTER D. BURLING, formerly at the University of Missouri, Columbia, Missouri, is at the Victoria Memorial Museum, Ottawa, Canada.

PHILSON DELP COLLINS, JR., formerly with the Kingwood Oil Company in Illinois, is with the Arabian-American Oil Company, Bahrein Island, Persian Gulf.

JOHN O'KEEFE, JR., has left the Richfield Oil Corporation, Long Beach, California. He is a consulting petroleum engineer at 205 South Sloan Avenue, Compton, California.

JOHN B. SOUTHER of Lincoln, Nebraska, is employed by the Honduras Timber and Exploration Company, San Pedro Sula, Honduras, Central America.

A. F. CRIDER, consulting geologist, has moved his office to 407 Giddens-Lane Building, Shreveport, Louisiana.

W. E. BIVENS, JR., is with the Sun Oil Company at McAllen, Texas.

Lieutenant Colonel OTTMAR F. KOTICK, formerly with the Associated Oil Company, Oildale, California, is overseas.

Captain ATLEE G. MANTHOS, of San Antonio, Texas, is in the Army Air Force.

Major PAUL K. GOODRICH, of Houston, Texas, has left Fort Bragg, North Carolina. His address is A.P.O. 15684, c/o Postmaster, New York.

Lieutenant Colonel DONALD E. MATHES, formerly of the Republic Producing Company, Houston, Texas, and recently at Fort Benning, Georgia, may be addressed: A.P.O. 18259, c/o Postmaster, New York.

KENNETH C. HEALD has been elected a vice-president of the Gulf Oil Corporation, Pittsburgh, Pennsylvania. PAUL D. FOOTE, of the Gulf Research and Development Corporation, also was elected a vice-president of the parent company.

A. J. GOODMAN, of the Socony-Vacuum Oil Company, presented a paper on "The Turner Valley Reservoir Condition" at a regular meeting of the Alberta Society of Petroleum Geologists held February 22, at the Palliser Hotel, Calgary, Alberta.

BENJAMIN T. SIMMONS, geologist for the General Crude Oil Company, has resigned to open a consulting office at 1209 Second National Bank Building, Houston, Texas.

JOHN P. LUKENS, with the Oklahoma Seismograph Company in Shawnee, Oklahoma' gave a lecture on "Seismograph" before the Shawnee Geological Society at a meeting held on March 1, in the Aldridge Hotel. Also a series of war films was shown.

ROBERT S. BREITENSTEIN may be addressed in care of Soc. Pet. Las Mercedes, Apartado 1429, Caracas, Venezuela.

ROBERT S. CLARK, formerly with the Midstates Oil Corporation at Wichita, Kansas, is in the employ of the Phillips Petroleum Company at Tallahassee, Florida.

LOUITA G. DODSON, previously employed by the Geophysical Service, Inc., is with the Sun Oil Company, Dallas, Texas.

KATHERINE F. GREACEN has left the Shell Oil Company, Inc., to join the Hunt Oil Company, Midland, Texas.

HAROLD K. SHEARER, now with Drilling and Exploration Company, Inc., in Brazil' was with the Office of Economic Warfare in 1943 and 1944, in coöperation with the Brazilian Departmento Nacional da Producao Mineral in strategic mineral work, searching particularly for quartz in the Araguaia River Basin of Pará. Shearer and Henrique Capper Alves de Souza are the authors of "Araguaia Recursos Minerais," *Boletim 61* (1944) of the Brazilian Divisao de Fomento da Producao Mineral. It is a bulletin of 54 pages, 21 photographs, 5 folded maps, and 2 text figures. It is in Portuguese.

W. J. MILLARD, Olney, Texas, is the author of *Boletim 60* (1944) of the Brazilian Divisao de Fomento da Producao Mineral, "Lavra de Mica por Meio de Stripping," a bulletin of 27 pages in Portuguese, 9 black-line illustrations, and 40 photographs. This is the first work on the use of the stripping method of mining Brazilian mica.

Lieutenant Colonel ED. W. OWEN, who has been in the Army Air Corps in the Pacific Region since 1943, has been in the United States a few weeks.

C. E. DOBBIN, of the United States Geological Survey, Denver, Colorado, spoke before the Wyoming Geological Association, at Casper, March 26, on "The Relationship of the Cretaceous and Tertiary Formations in the Synclinal Basins."

CHARLES C. WILLIAMS, formerly with the General Geophysical Company of Houston, is now associated with the Seismic Engineering Company in Dallas. His address is in care of this company, Box 1565, Dallas, Texas.

JOHN P. LEWIS has left the Pure Oil Company to join the geological staff of the Sohio Oil Company, Mt. Pleasant, Michigan.

ROY LEBKICHER has returned from Saudi Arabia. His address is Arabian American Oil Company, 200 Bush Street, San Francisco, California.

JOHN M. KELLY, recently State geologist of New Mexico, is now production superintendent with George P. Livermore, Inc., Lubbock, Texas.

HUBERT GUYOD, of the Halliburton Oil Well Cementing Company, presented a paper entitled "Recent Trends in Electrical Log Interpretations," before the Houston Geological Society, March 15.

CARL B. RICHARDSON, of the Barnsdall Oil Company, spoke on "Sedimentation of the Gulf Coast," at the meeting of the Tulsa Geological Society, March 18.

LOUIS C. ROBERTS, JR., formerly with the Alder Oil Company, Houston, is now with the Hunt Oil Company, Dallas, Texas.

REINHARD A. STEINMAYER, professor of geology and head of the department of geology at Tulane University, has been elected president of the Louisiana Engineering Society, New Orleans. His photograph forms the frontispiece of the *Proceedings* of the Society in the February, 1945, issue.

F. STEARNS MACNEIL, of the United States Geological Survey, discussed "The Effect of Solution on the Surface Geology of Eastern Alabama and Georgia," at the meeting of the Shreveport Geological Society, March 12, 1945.

ALLEN EHLERS, district geologist with the Carter Oil Company at Seminole for the past year and a half, has resigned to join the geological staff of the Skelly Oil Company at Tulsa.

W. C. CLARK has left the British-American Oil Producing Company at Casper, Wyoming, to accept a position with the Independent Exploration Company at Houston, Texas.

WILLIAM L. RUSSELL is in the employ of the Stanolind Oil and Gas Company, Tulsa, Oklahoma.

CHARLES W. HENDERSON, of the United States Bureau of Mines, Denver, Colorado, died on January 26, at the age of 59 years.

JAMES F. RALSTIN, of Wichita, Kansas, was captured while in overseas service at Cisterna, Italy, early in 1944. He is a prisoner of war in Germany.

The annual business meeting of the Society of Economic Geologists was held in New York City, February 20. New officers announced are: president-elect (1946), W. O. HOTCHKISS; first vice-president-elect (1946), J. TERRY DUCE; councilors (1945–47), GEORGE M. FOWLER, F. M. CAMERON, T. G. MOORE; regional vice-presidents (1945), ALFRED BRAMMALL (Europe), J. M. S. KRISHMAN (Asia), R. A. PELLETIER (Africa), GEORGE HANSON (North America), O. H. LEONARDOS (South America), R. LOCKHART JACK (Australia). The retiring president, JOHN M. BOUTWELL, addressed the meeting on the subject of "Economic Geology." Current officers are: president, O. E. MEINZER, United States Geological Survey; first vice-president, T. B. NOLAN, United States Geological Survey; secretary, C. H. BEHRE, JR., Columbia University, New York; treasurer, J. T. SINGEWALD, JR., Johns Hopkins University, Baltimore.

The Michigan Geological Society held its annual election meeting at Morrill Hall on the Michigan State College Campus at East Lansing, Michigan, on February 16. New

officers elected for the term of 1945 are: president, KENNETH K. LANDES, department of geology, University of Michigan, Ann Arbor; vice-president, T. J. WEAVER, Michigan Consolidated Gas Company, 411 Murray Building, Grand Rapids; secretary-treasurer, MANLEY OSGOOD, JR., Cities Service Oil Company, Box 149, Mt. Pleasant; business manager, HARRY HARDENBERG, Department of Conservation, Capitol Savings and Loan Bldg., Lansing.

DISTINGUISHED LECTURE TOURS

WILLIAM C. KRUMBEIN, Beach Erosion Board, United States War Department, Washington, D. C., made an extensive tour of the affiliated societies during February and March, discussing "Modern Sedimentation and the Search for Petroleum."

In his talk before twenty different groups, Dr. Krumbein stressed the importance of variations in sedimentary characteristics in the location of oil accumulations, and outlined advanced techniques to reveal significant sedimentational data.

The following societies participated in the tour:

February 16—Southeastern Geological Society at Tallahassee
19—New Orleans Geological Society at New Orleans
20—Mississippi Geological Society at Jackson
21—Shreveport Geological Society at Shreveport
22—Houston Geological Society at Houston
23—South Louisiana Geological Society at Lake Charles
26—East Texas Geological Society at Tyler
27—North Texas Geological Society at Wichita Falls
28—Ardmore Geological Society at Ardmore
March 1—Fort Worth Geological Society at Fort Worth
2—West Texas Geological Society at Midland
3—Texas Technological College at Lubbock
5—Tulsa Geological Society at Tulsa
6—Tulsa Geological Society at Bartlesville
7—Kansas Geological Society at Wichita
9—Rocky Mountain Association at Denver
13—Casper Geologists Club at Casper
16—Alberta Geological Society at Calgary
21—Pittsburgh Geologists at Pittsburgh
April 2—New York Academy of Sciences at New York

M. KING HUBBERT, research geophysicist, Shell Oil Company, Houston, Texas, presented a lecture entitled "The Strength of the Earth" before the affiliated societies during the latter part of March and early in April. He discussed the paradox of an earth made up of hard rock which has been deformed repeatedly as if composed of extremely weak and plastic materials, and analyzed the reasons for the existence of this apparent discrepancy in behavior.

Dr. Hubbert appeared before the following societies.

March 21—South Louisiana Geological Society at Lake Charles
23—Southeastern Geological Society at Tallahassee, Florida
26—Mississippi Geological Society at Jackson, Mississippi
28—Shreveport Geological Society at Shreveport, Louisiana
29—Fort Worth Geological Society at Forth Worth, Texas
30—West Texas Geological Society at Midland, Texas
April 2—Dallas Petroleum Geologists at Dallas, Texas
3—Tulsa Geological Society and Society of Exploration Geophysicists at Tulsa, Oklahoma
6—Corpus Christi Geological Society at Corpus Christi

JOHN L. FERGUSON, *chairman*

ADDITIONAL MEMBERSHIP APPLICATIONS APPROVED

(Continued from page 468)

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Meetings will be announced.

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Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

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Vice-President and Program Chm. - B. E. Bremer
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The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive. 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Union Producing Co., Box 1407, Zone 92

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

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Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Cities Service Oil Co., Box 149, Mt. Pleasant
Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey, Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

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Union Producing Company

Secretary-Treasurer - - - - Frederic F. Mellen
British-American Oil Producing Company
1007 Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

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Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

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State Capitol

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Sinclair Prairie Oil Company
703 Colcord Building

Secretary-Treasurer - - - - - - C. E. Hamilton
Consolidated Gas Utilities Corporation
814 Braniff Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday, at 12:00 noon. Y.W.C.A. Cafeteria.

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SHAWNEE, OKLAHOMA

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Vice-President - - - - - - - John P. Lukens
Oklahoma Seismograph, 1103 North Philadelphia

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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TULSA, OKLAHOMA

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Editor - - - - - - - - - Roy L. Ginter
U. S. Geological Survey

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

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Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

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Trowbridge Sample Service

Secretary-Treasurer - - - - - G. T. Buskirk
Stanolind Oil and Gas Company, Box 660

Meetings: Regular meetings at 7:30 P.M., the second Monday, each month, City Hall. Luncheons: Noon, fourth Monday, each month, Blackstone Hotel.

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Vice-President - - - - - - William J. Nolte
Stanolind Oil and Gas Company, Box 1410

Secretary-Treasurer - - - Spencer R. Normand
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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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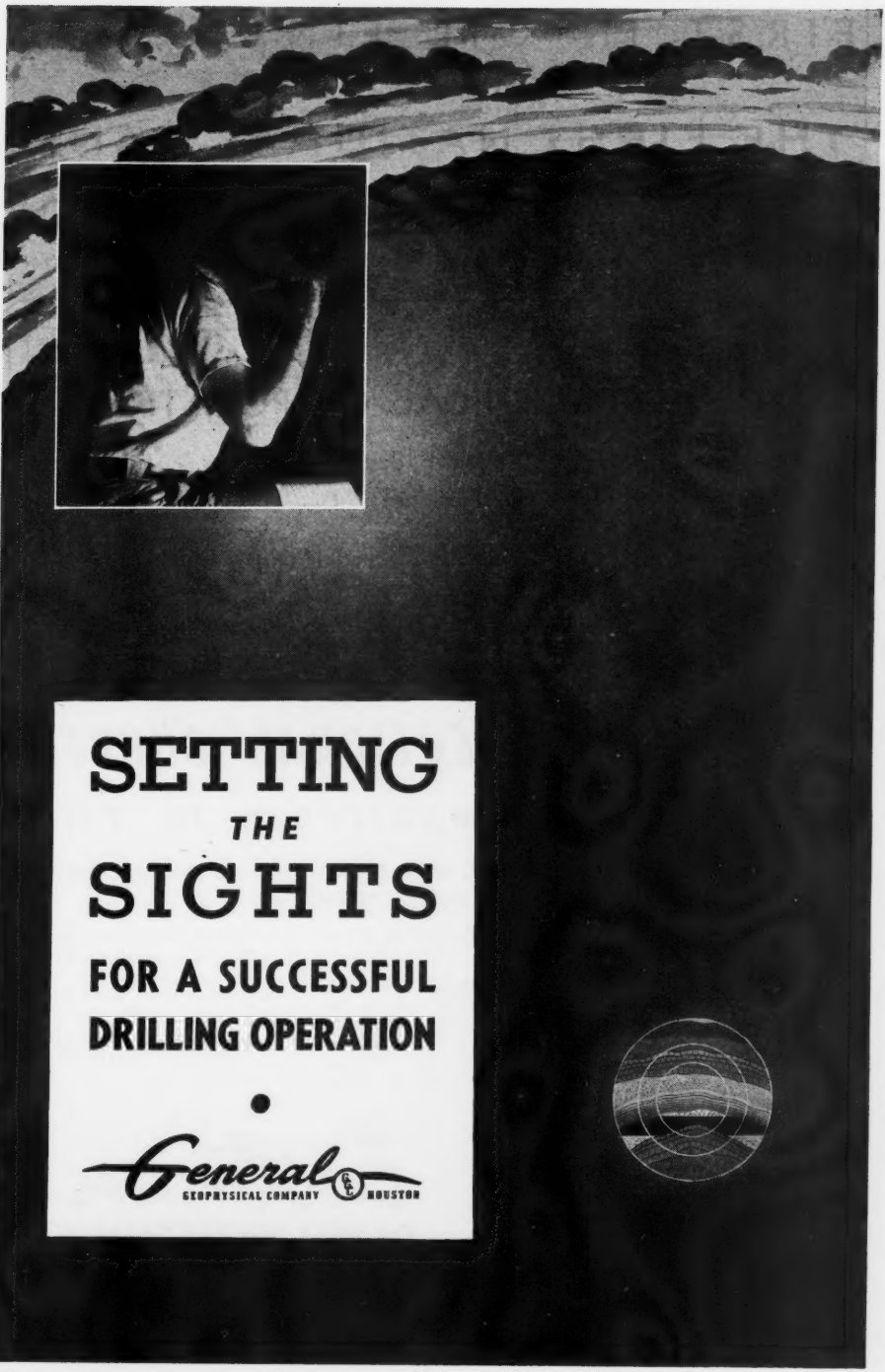
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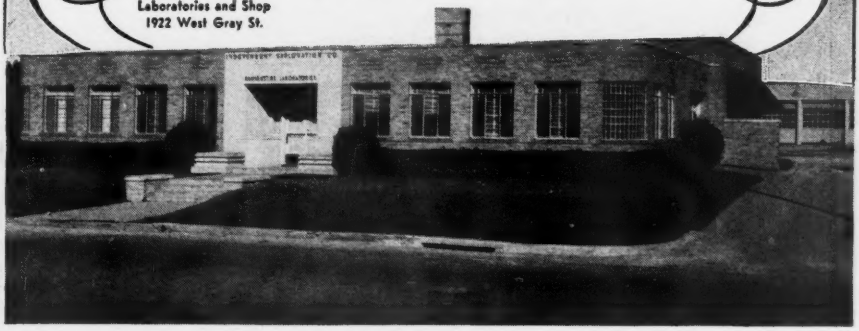

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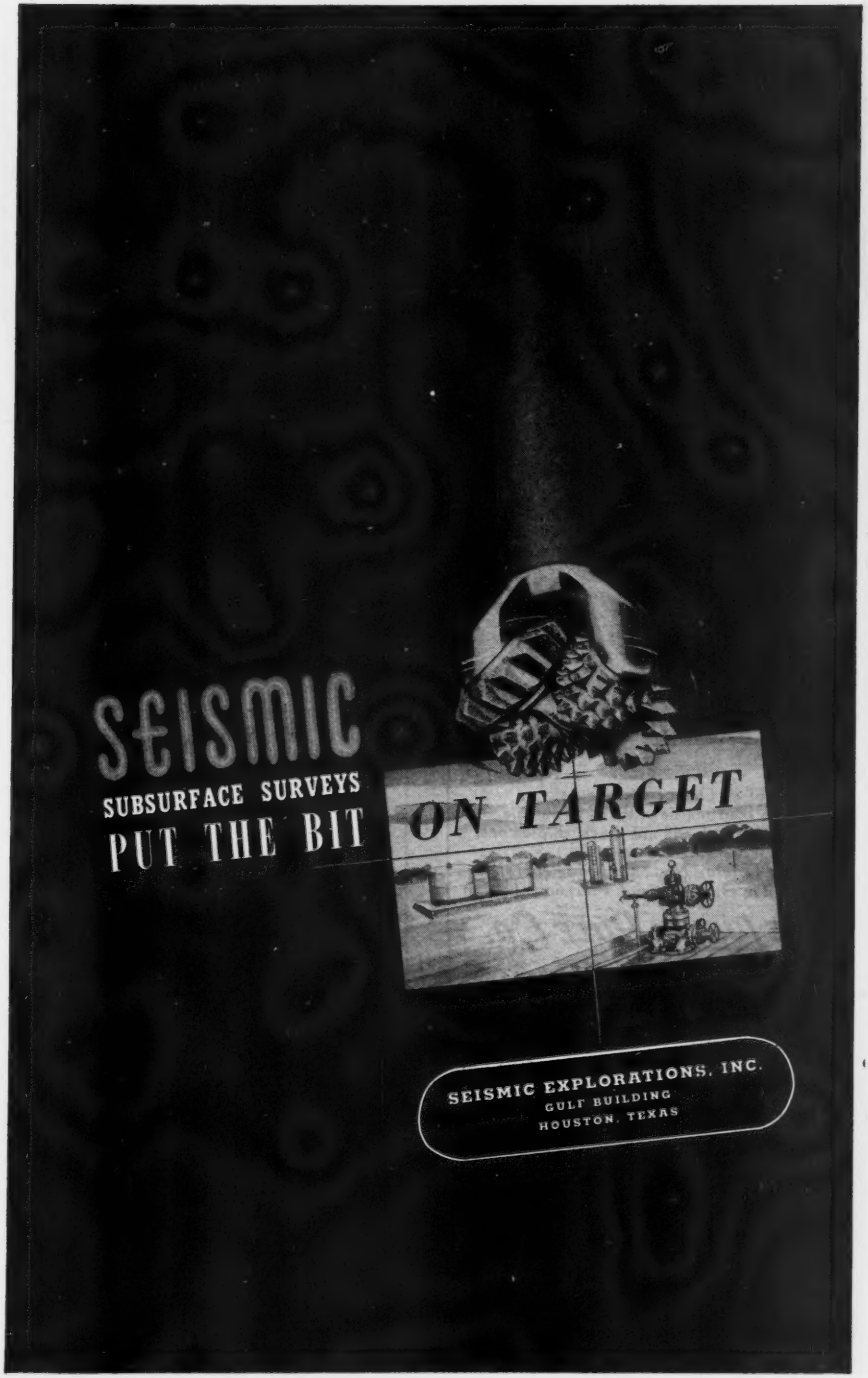
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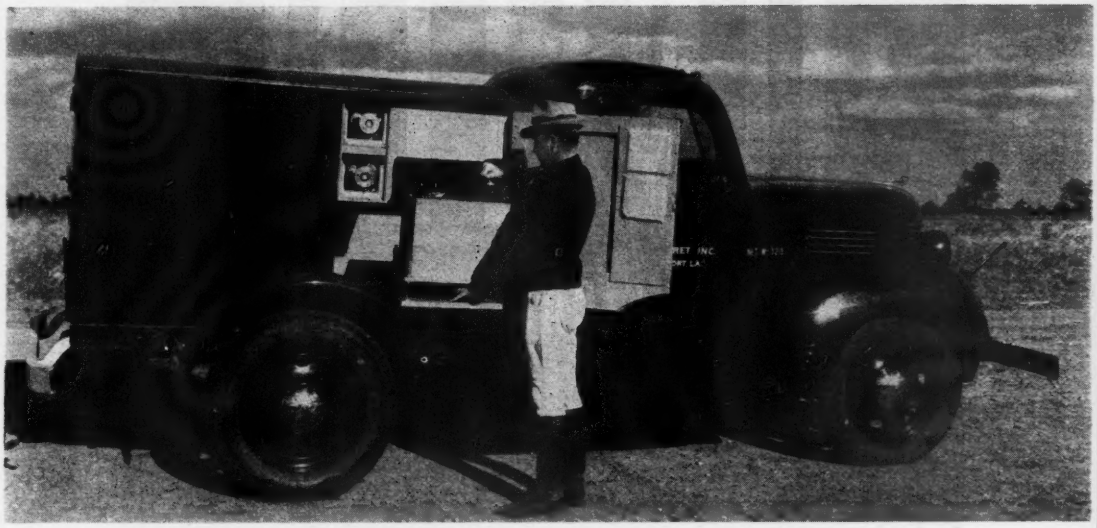

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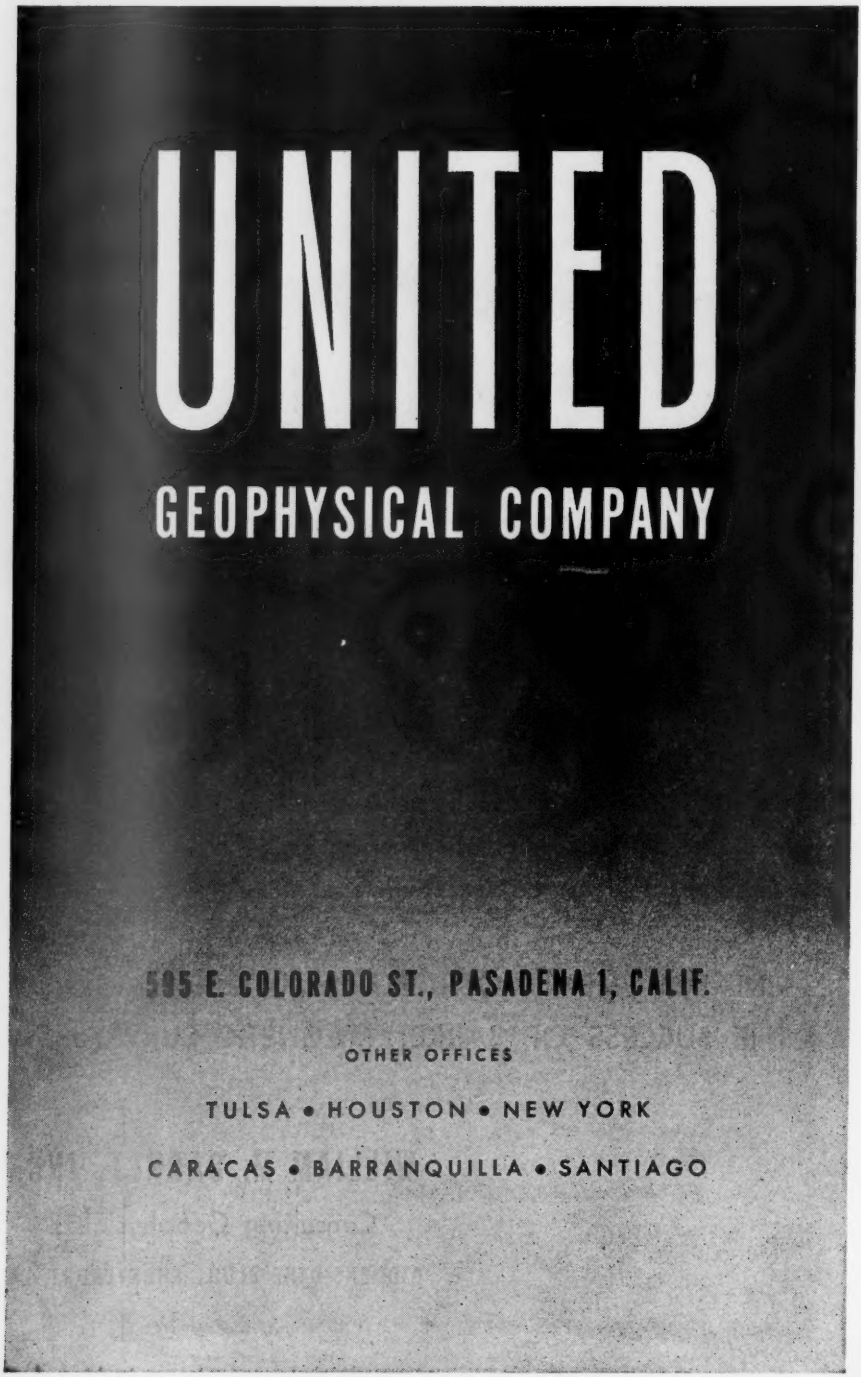
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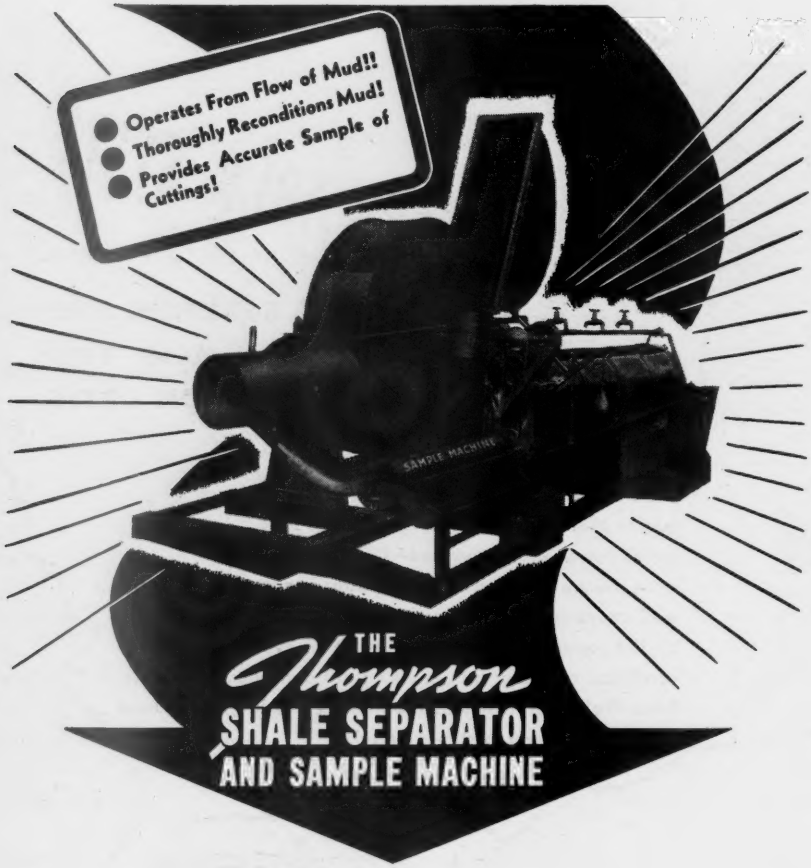

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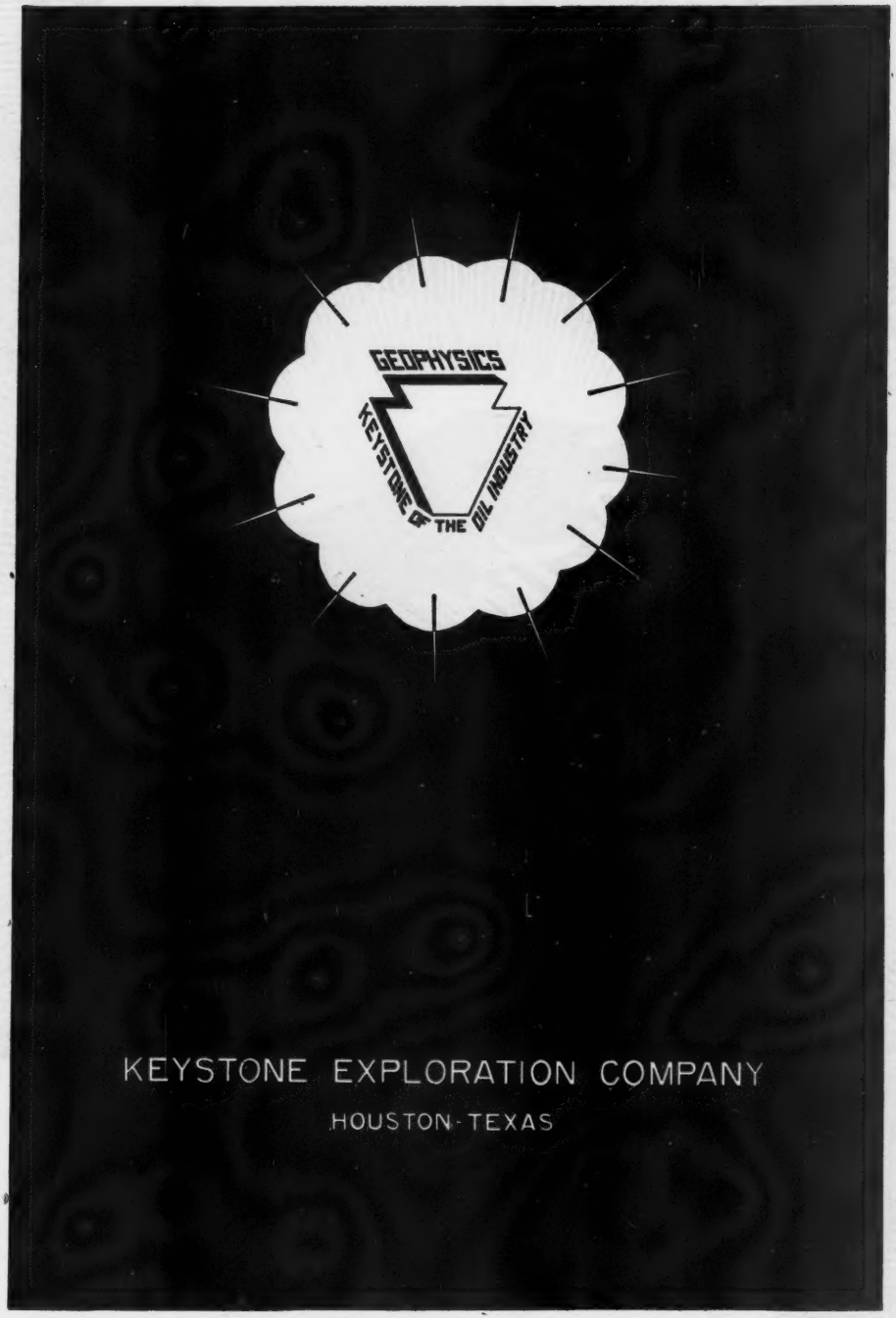
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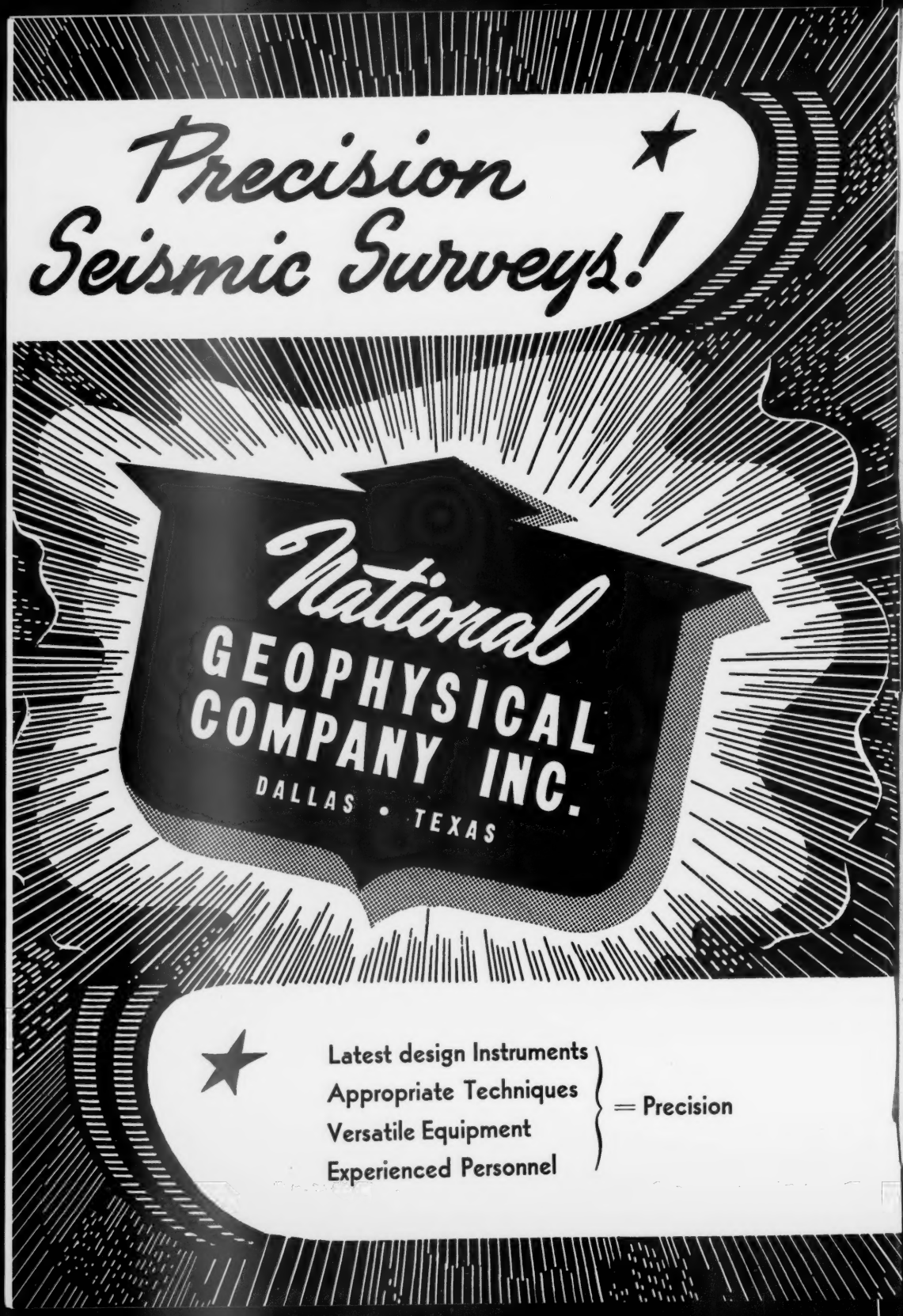
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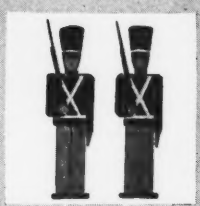

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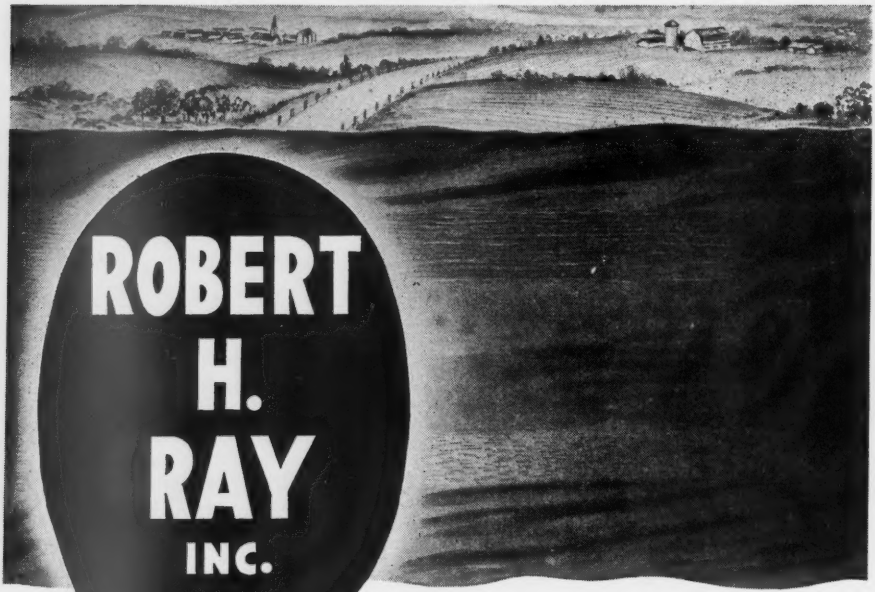

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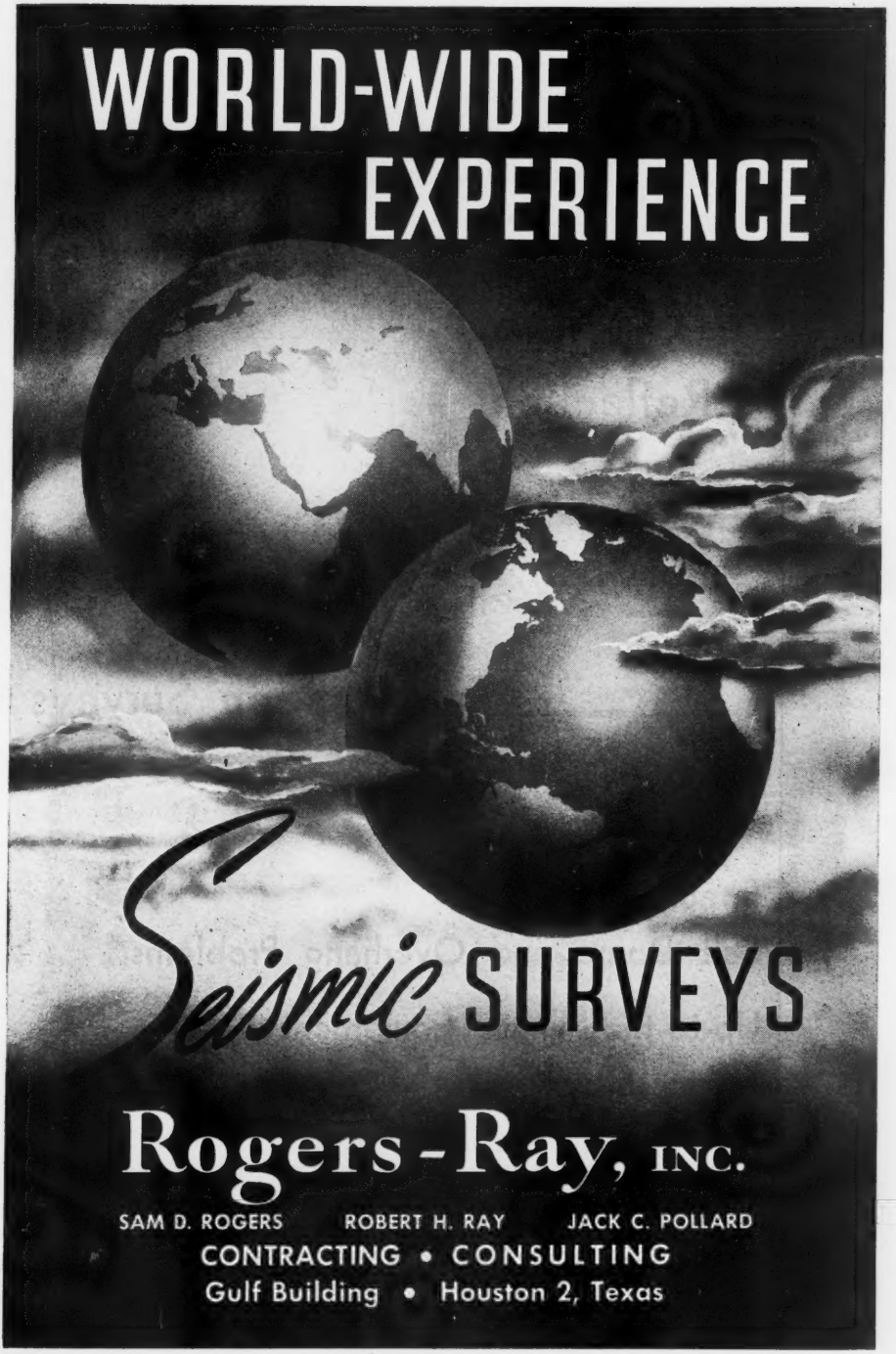
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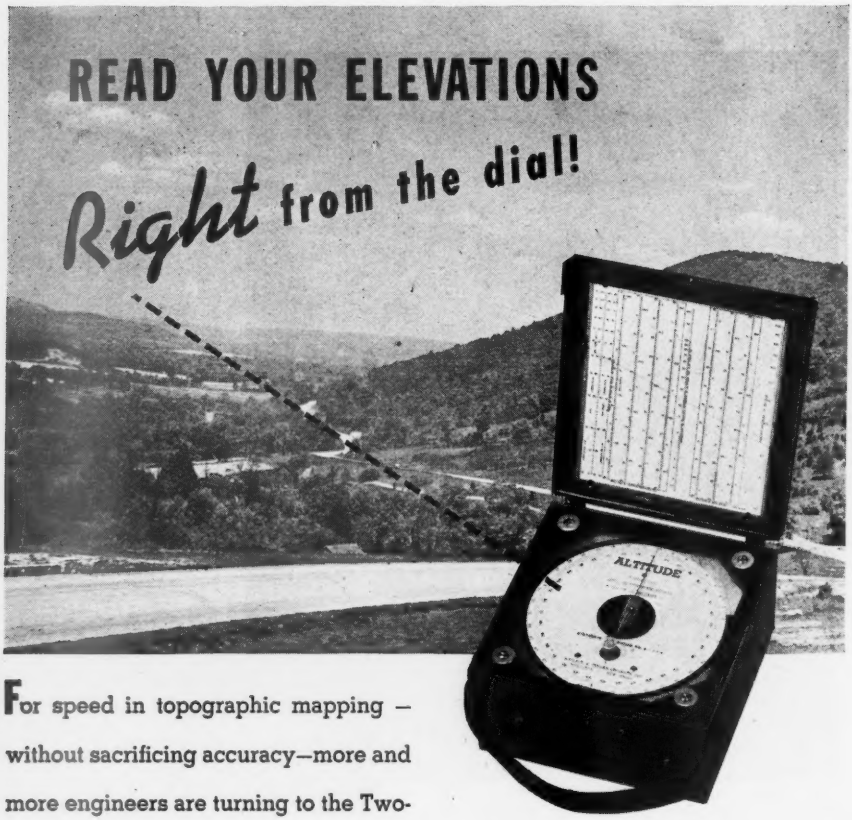

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by

F. M. VAN TUYL AND W. S. LEVINGS

With the cooperation of members of the staffs of the Departments of Geology, Geophysics, and Petroleum Engineering of the Colorado School of Mines

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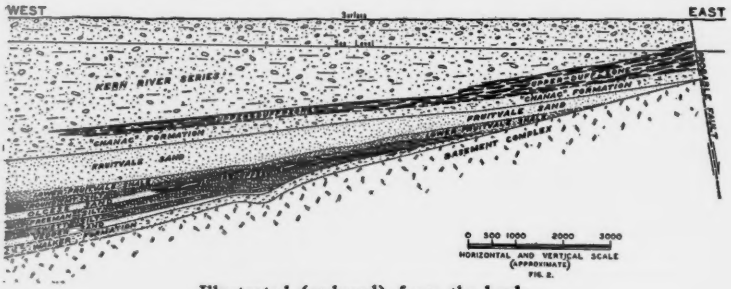

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FIG. 20.—Cerro Bernal, volcanic plug. (Reproduction of sketch by Captain G. F. Lyon, 1828; redrawn by F. S. Howell.)

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By JOHN M. MUIR
1936

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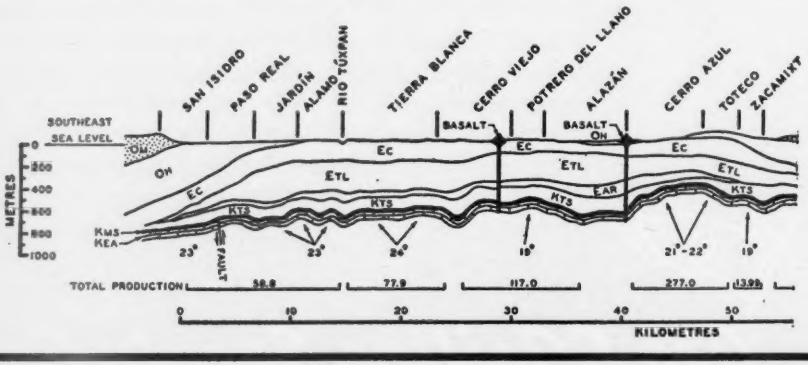

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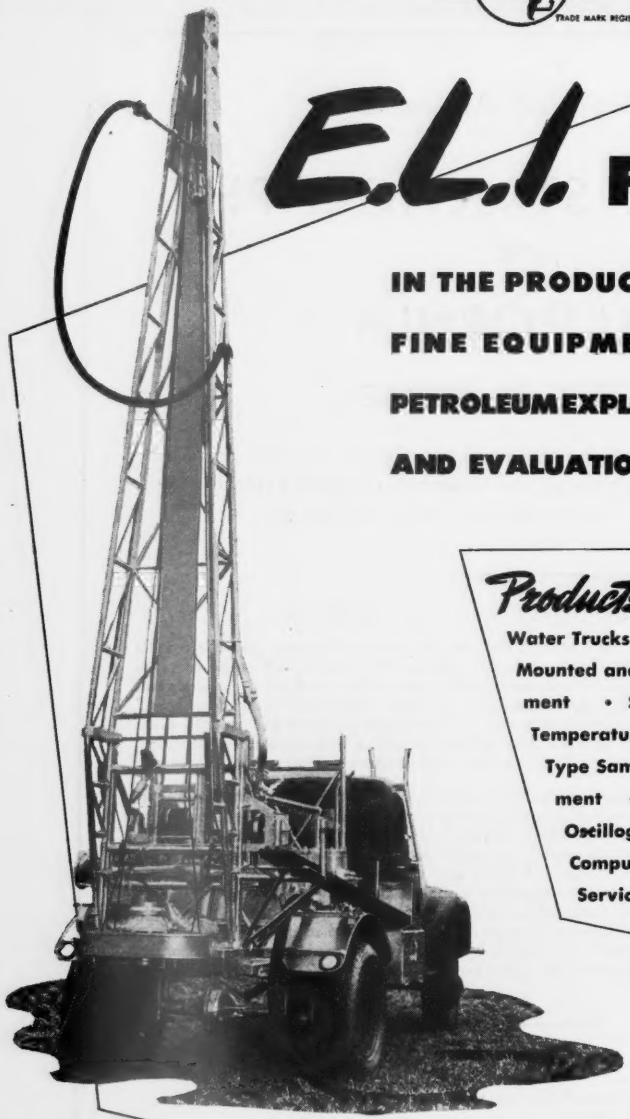

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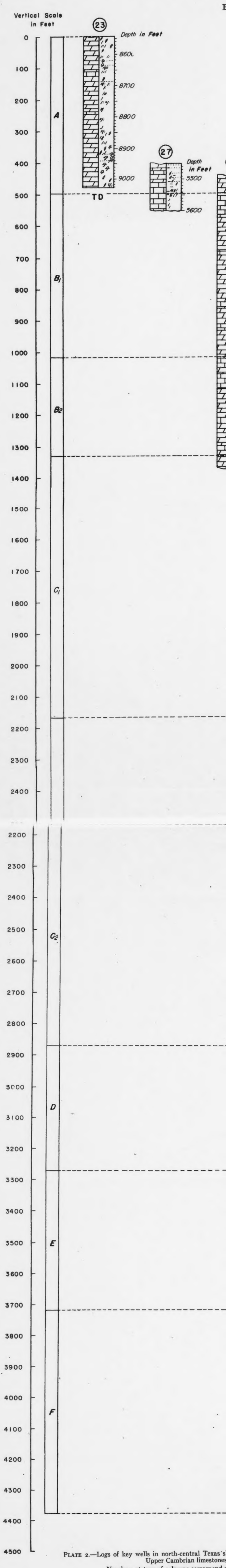
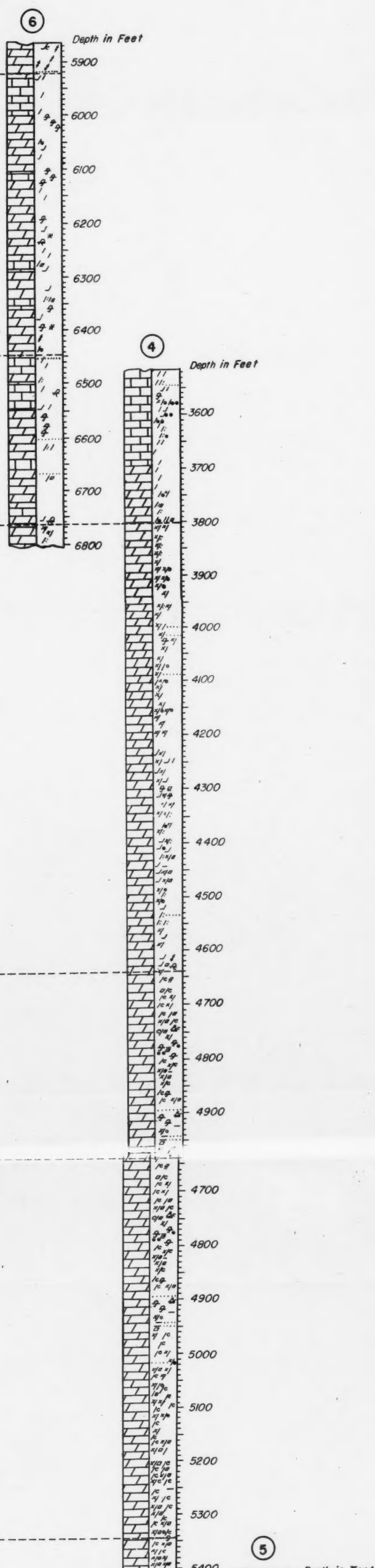


PLATE 2.—Logs of key wells in north-central Texas s
Upper Cambrian limestones
Numbers at tops of columns correspond w

LIST OF WELL

Index No.	*County*	*Operator*	*Well No.*	*Farm*
23	Denton	A. G. Carter *et al.*	1	Allen
27	Somervell	M. E. Davis *et al.*	1	Cousins
6	Montague	Sinclair Prairie Oil Co.	2	Doty
4	Wichita	Deep Oil Development Co.	1	Hirschi
5	Clay	The Texas Co.	41	Byerts



Texas showing sequence of Lower Ordovician and
nestones and dolomites.
spond with well numbers in Plate 1.

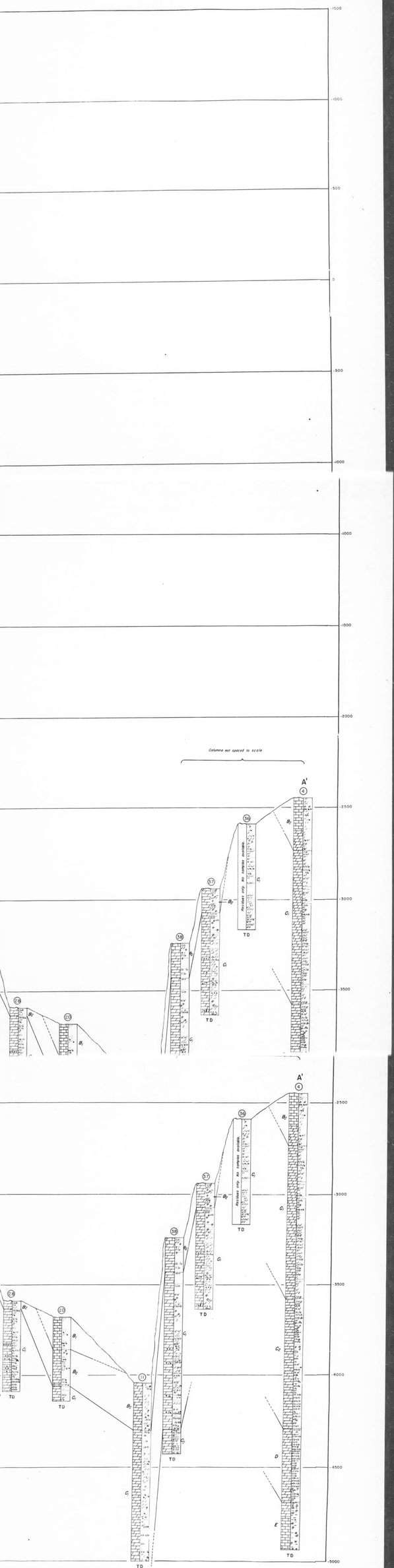
OF WELLS

Farm	Land Survey	Location
n	S. Westbrook	440 ft. from north line and 440 ft. from west line of 640-acre tract
sins y	John Echols J. H. Jones	East corner of 50-acre tract 426 ft. from east line and 494 ft. from south line of survey10 miles from west county line and 1 mile south of Red River
schi	D. Cowan	
rts	Gaston	Byerts Subdivision, Block 19

Plate 2.—Cross section *AA'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.
Line of cross section shown in Plate 1.
Numbers at top of columns correspond with well numbers in Plate 1.

List of Wells

Fig. 3 Pl. 2	County	Operator	Well No.	Farm	Land Survey	Location
33 32 31	McCulloch Brown Eastland	City of Brady Ruffin & Dunnell J. H. Hopkins	3 1 1	City of Brady Baugh Davis	O. Talbot H. & T.C.R.R.	City of Brady Sec. 46, Block 4, Sec. 14, 8,001 ft. from south and 330 ft. west of NE. cor. of Sec. 1
28	Stephens	Shell Oil Co.	1	Allen	S.P.R.R.	Block 5, Sec. 19, 491 ft. from south and 1,320 ft. from east line
29	Young	Standard Oil Co. of Texas	1	Halbert	T.E. & L.R.R.	Sec. 196, 2,002 ft from south and 1,320 ft. from east line of E. 1
23	Archer	Phillips Petroleum Co.	1	Pendry	H. & T.C.R.R.	Block 4, Sec. 13, 660 ft. from south and 1,320 ft. from west line of 160-acre tract
36	Wichita	Deep Oil Development Co.	1	Munger A	Kemps Wichita Valley Farms	330 ft. from north line and 1,320 ft. from west line of Sec. 8
37	Wichita	Shell Oil Co. et al.	18E	Preston A	H. & T.C.R.R.	1,162 ft. from south and 1,320 ft. from west line of Sec. 21, Block 3
35	Wichita	Gulf Oil Corp.	432A	Burnette	H.T. & B.R.R.	1,320 ft. from north and 469 ft. from west line of E. 4,
4	Wichita	Deep Oil Development Co.	1	Hirschi	D. Cowan	12 miles from west county line and 1 mile south of Red River


-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Columns not spaced to scale
A'
4
36
37
38
11
28
29
TD
Pleistocene sands, clay and gravel
Pleistocene sands and clay
Pliocene sands and clay
B1
B2
C1
C2
D
E

Scale in Feet
Below Sea Level

0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000
- 1100
- 1200
- 1300
- 1400
- 1500
- 1600
- 1700
- 1800
- 1900
- 2000
- 2100
- 2200
- 2300
- 2400
- 2500
- 2600
- 2700
- 2800
- 2900
- 3000
- 3100
- 3200
- 3300
- 3400
- 3500
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- 3700
- 3800
- 3900
- 4000
- 4100
- 4200
- 4300
- 4400
- 4500
- 4600
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- 4900
- 5000
- 5100
- 5200
- 5300
- 5400
- 5500
- 5600
- 5700
- 5800
- 5900
- 6000
- 6100
- 6200
- 6300
- 6400
- 6500
- 6600
- 6700

B

35

B_1

B_2

C_1

C_2

D

E

TD

34

B_1

B_2

C_1

C_2

D

TD

27

A

B_1

B_2

TD

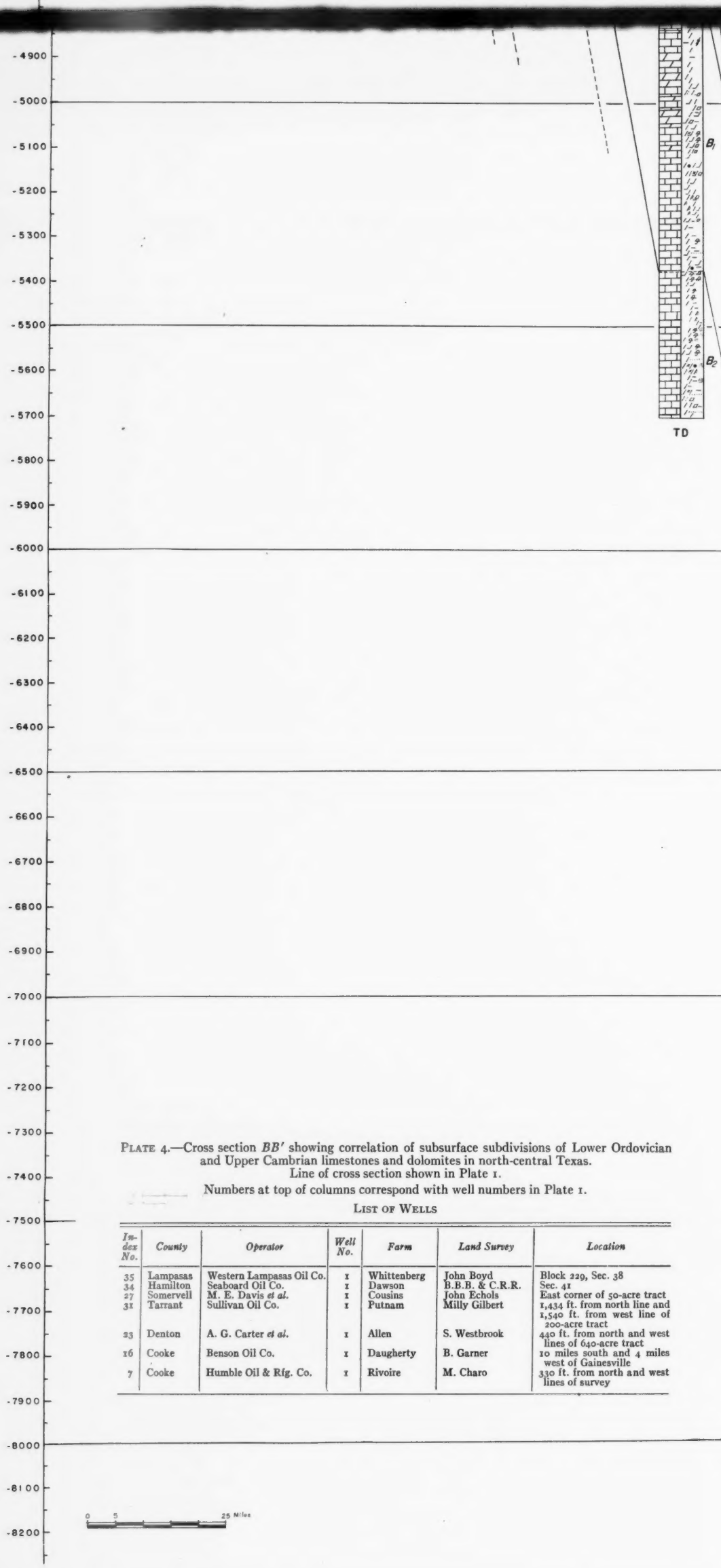
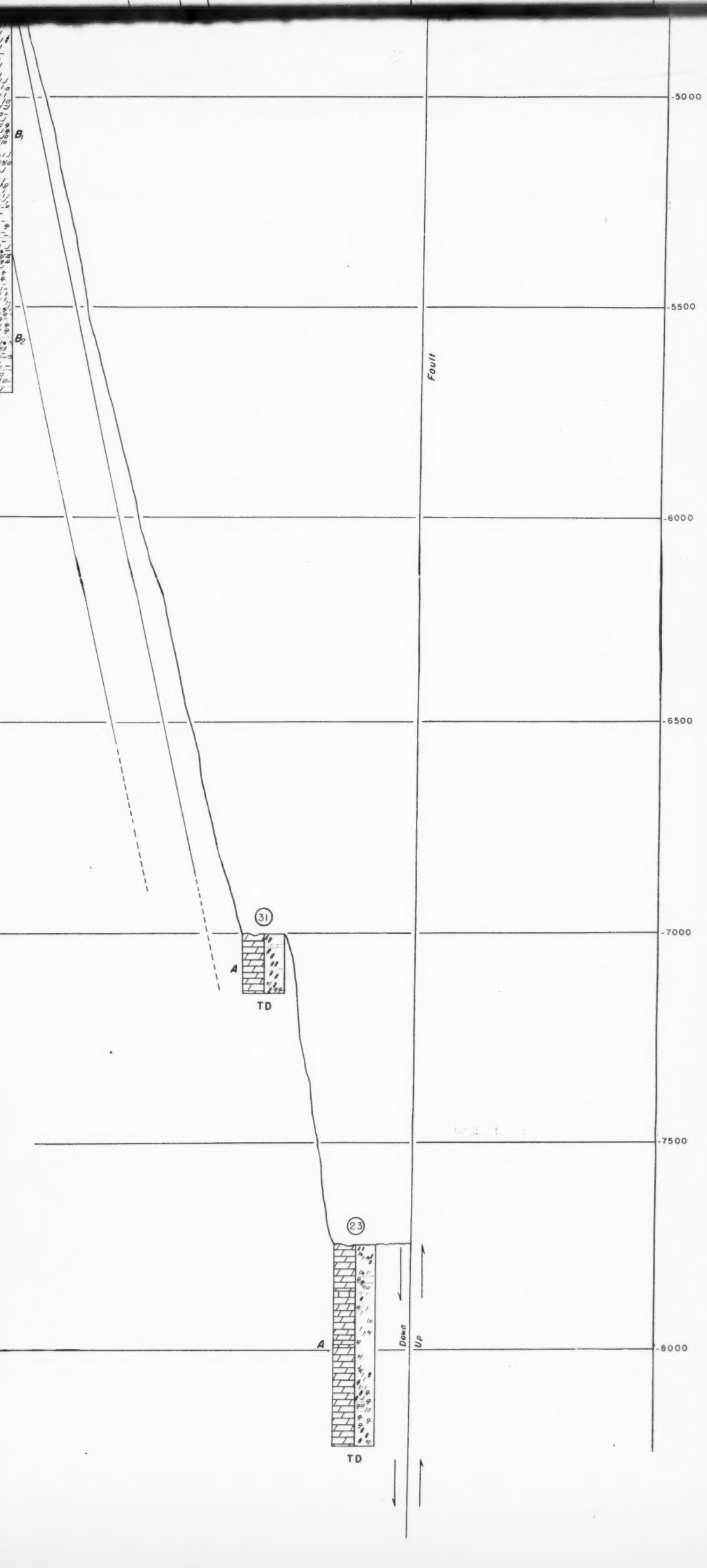


PLATE 4.—Cross section *BB'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.
Line of cross section shown in Plate 1.
Numbers at top of columns correspond with well numbers in Plate 1.

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
35	Lampasas	Western Lampasas Oil Co.	1	Whittenberg	John Boyd	Block 229, Sec. 38
34	Hamilton	Seaboard Oil Co.	1	Dawson	B.B.B. & C.R.R.	Sec. 41
27	Somervell	M. E. Davis *et al.*	1	Cousins	John Echols	East corner of 50-acre tract
31	Tarrant	Sullivan Oil Co.	1	Putnam	Milly Gilbert	1,434 ft. from north line and 1,540 ft. from west line of 200-acre tract
23	Denton	A. G. Carter *et al.*	1	Allen	S. Westbrook	440 ft. from north and west lines of 640-acre tract
16	Cooke	Benson Oil Co.	1	Daugherty	B. Garner	10 miles south and 4 miles west of Gainesville
7	Cooke	Humble Oil & Rfg. Co.	1	Rivoire	M. Charo	330 ft. from north and west lines of survey


B1
B2
Fault
-5000
-5500
-6000
-6500
-7000
-7500
-8000
31
A
TD
23
A
Down
Up
TD

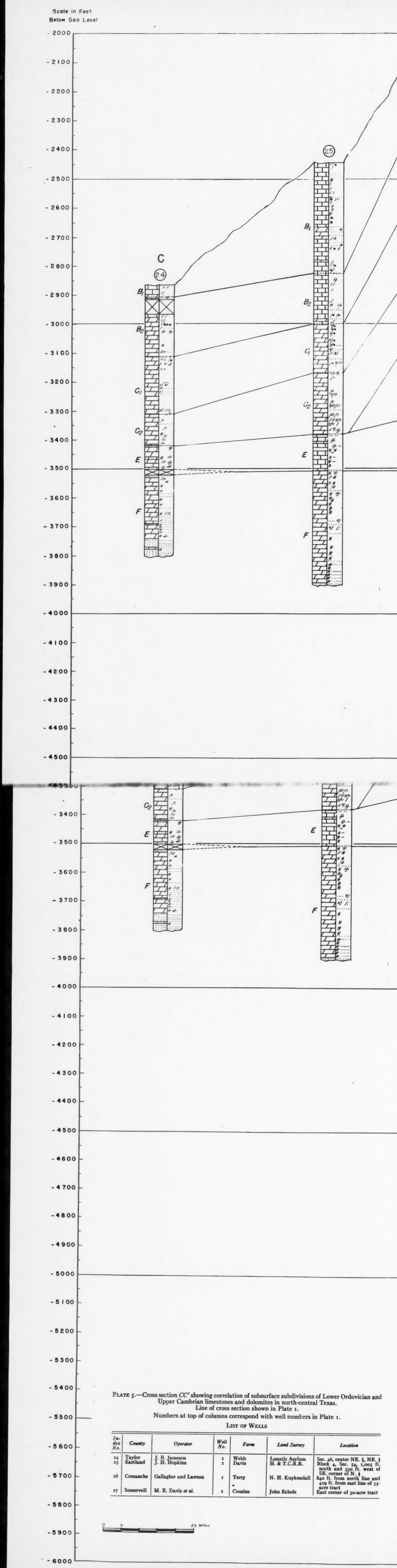
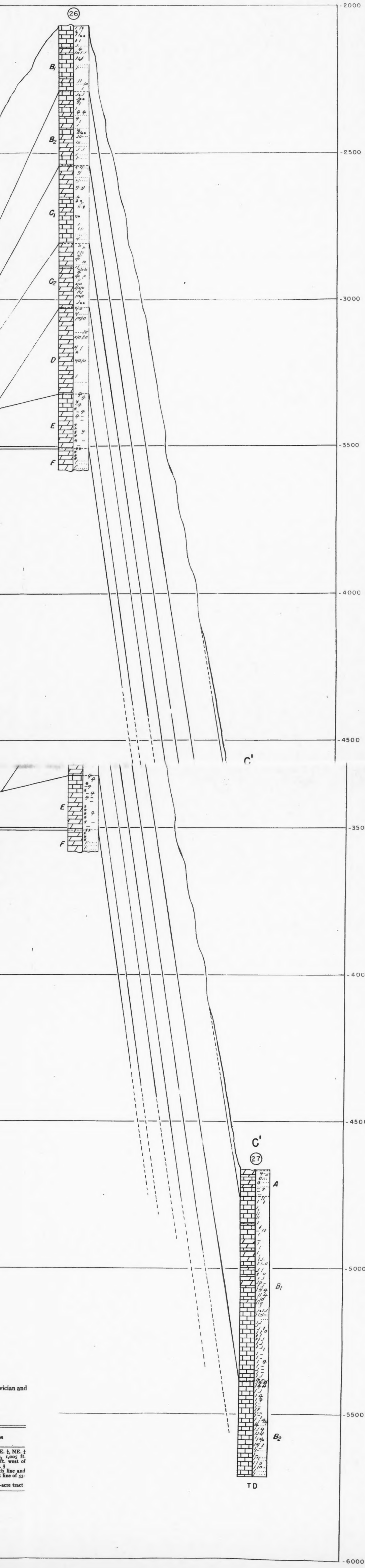


PLATE 5.—Cross section *CC'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.
Line of cross section shown in Plate 1.
Numbers at top of columns correspond with well numbers in Plate 1.

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
24	Taylor	J. B. Jameson	1	Webb	Lunatic Asylum	Sec. 46, center NE. ¼, NE. ¼
25	Eastland	J. H. Hopkins	1	Davis	H. & T.C.R.R.	Block 4, Sec. 54, 1,005 ft. north and 330 ft. west of SE. corner of N. ½
26	Comanche	Gallagher and Lawson	1	Terry	N. H. Kuykendall	840 ft. from north line and 429 ft. from east line of 53-acre tract
27	Somervell	M. E. Davis *et al.*	1	Cousins	John Echols	East corner of 50-acre tract



vician and

E. ¼, NE. ¼
, 1,005 ft.
ft. west of
¼
th line and
line of 53-

-acre tract

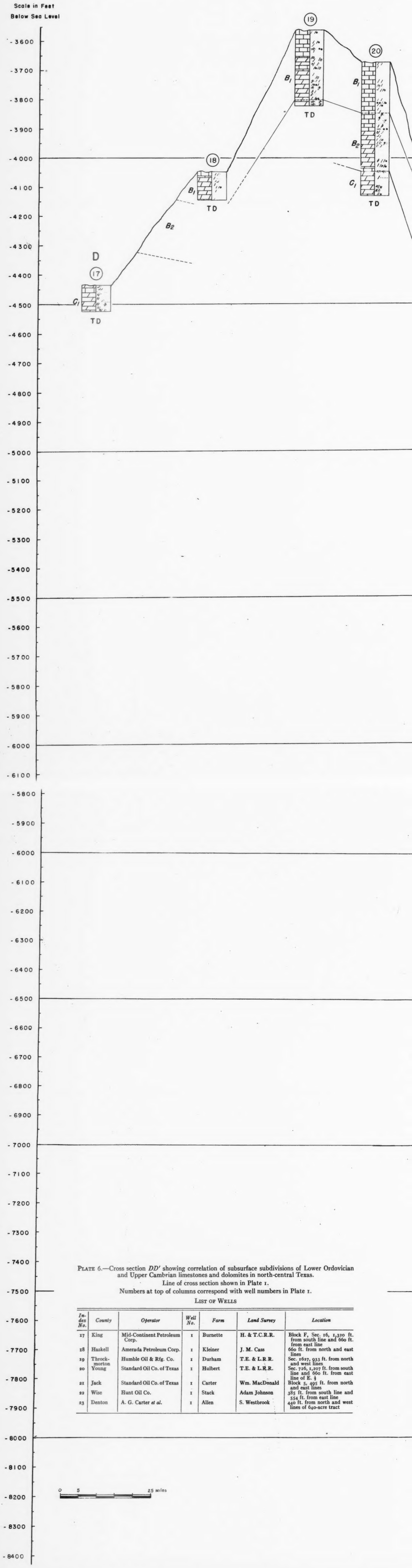


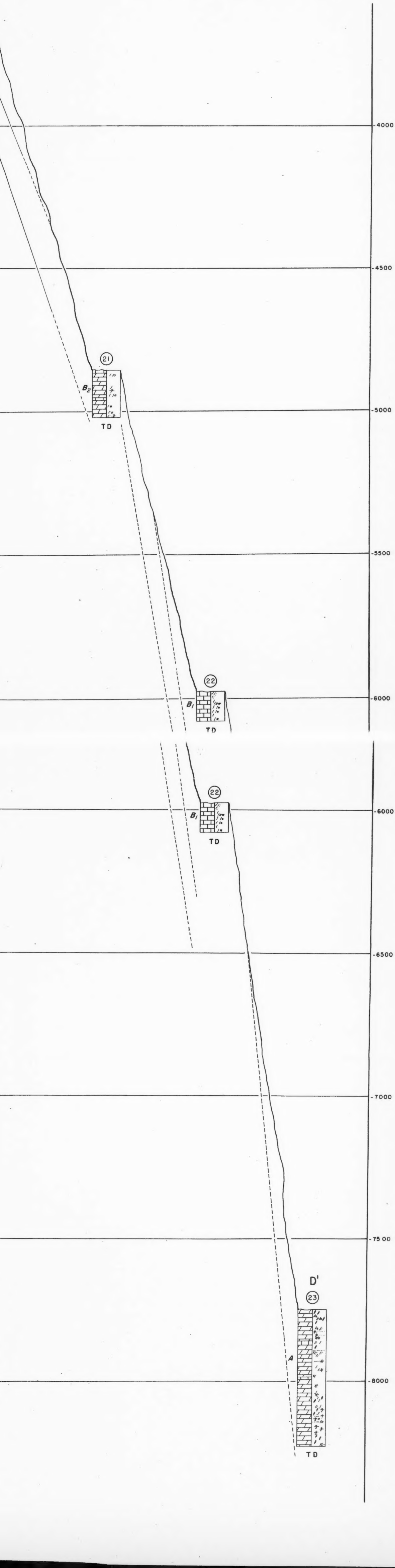
PLATE 6.—Cross section *DD'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.

Line of cross section shown in Plate 1.

Numbers at top of columns correspond with well numbers in Plate 1.

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
17	King	Mid-Continent Petroleum Corp.	1	Burnette	H. & T.C.R.R.	Block F, Sec. 16, 1,320 ft. from south line and 660 ft. from east line
18	Haskell	Amerada Petroleum Corp.	1	Kleiner	J. M. Cass	660 ft. from north and east lines
19	Throck-morton	Humble Oil & Rfg. Co.	1	Durham	T.E. & L.R.R.	Sec. 1627, 933 ft. from north and west lines
20	Young	Standard Oil Co. of Texas	1	Hulbert	T.E. & L.R.R.	Sec. 726, 1,207 ft. from south line and 660 ft. from east line of E. ½
21	Jack	Standard Oil Co. of Texas	1	Carter	Wm. MacDonald	Block 5, 495 ft. from north and east lines
22	Wise	Hunt Oil Co.	1	Stack	Adam Johnson	385 ft. from south line and 554 ft. from east line
23	Denton	A. G. Carter *et al.*	1	Allen	S. Westbrook	440 ft. from north and west lines of 640-acre tract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-5000
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-6000
-6500
-7000
-7500
-8000
21
B2
TD
22
B1
TD
22
B1
TD
D'
23
A
TD

PLATE 7.—Cross section *EE'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.

Line of cross section shown in Plate 1.

Numbers at top of columns correspond with well numbers in Plate 1.

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
8	Foard	The Texas Co.	3	Johnson	S.P.R.R.	Sec. 36
9	Foard	The Texas Co.	1	Margaret Unit	H. & T.C.R.R.	Block 4, Sec. 431, 990 ft. from north line and 330 ft. from west line
10	Wilbarger	Wilcox Oil Co.	1-MM	Waggoner	H. & T.C.R.R.	Block 17, Sec. 8, Center NE ¼, NE. ¼
11	Archer	Phillips Petroleum Co.	1	Pendry	H. & T.C.R.R.	Block 4, Sec. 13, 660 ft. from south and west lines of 160-acre tract
12	Archer	Bass & Dillard	1	McGregor	E. Goodwin	467 ft. from north and west lines of 144-acre tract
13	Clay	Shell Oil Co.	1	Coleman	Calhoun County School	Lot 24, 252 ft. from north line and 467 ft. from east line
14	Montague	Continental Oil Co.	1	Mueller	F. Hamilton	467 ft. from southeast and southwest lines of NE. 166-acre tract
15	Montague	Sinclair Prairie Oil Co.	1	Jones	I. Singletary	1,400 ft. from west line and 467 ft. from north line
16	Cooke	Benson Oil Co.	1	Daugherty	B. Garner	10 miles south and 4 miles west of Gainesville

E'

16

C1

C2

TD

-500

-1000

-1500

-2000

-2500

-3000

-3000

-3500

-4000

-4500

12

B1

B2

TD

Fault

-5000

-5500

13

A

B

-4500

12

B1

B2

TD

Fault

-5000

-5500

13

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Down

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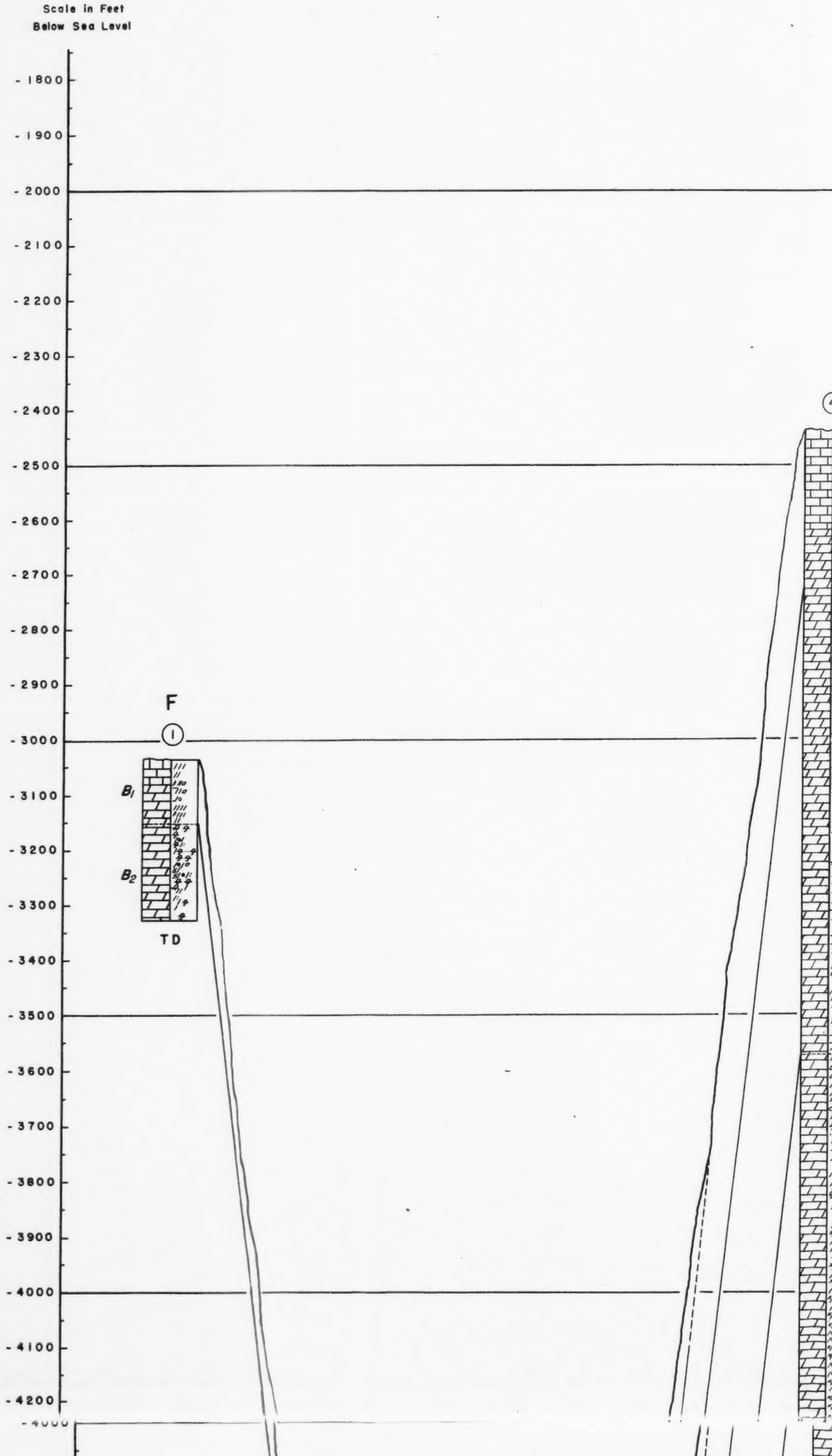
Scale in Feet
Below Sea Level
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- 2000
- 2100
- 2200
- 2300
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- 2500
- 2600
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- 3000
- 3100
- 3200
- 3300
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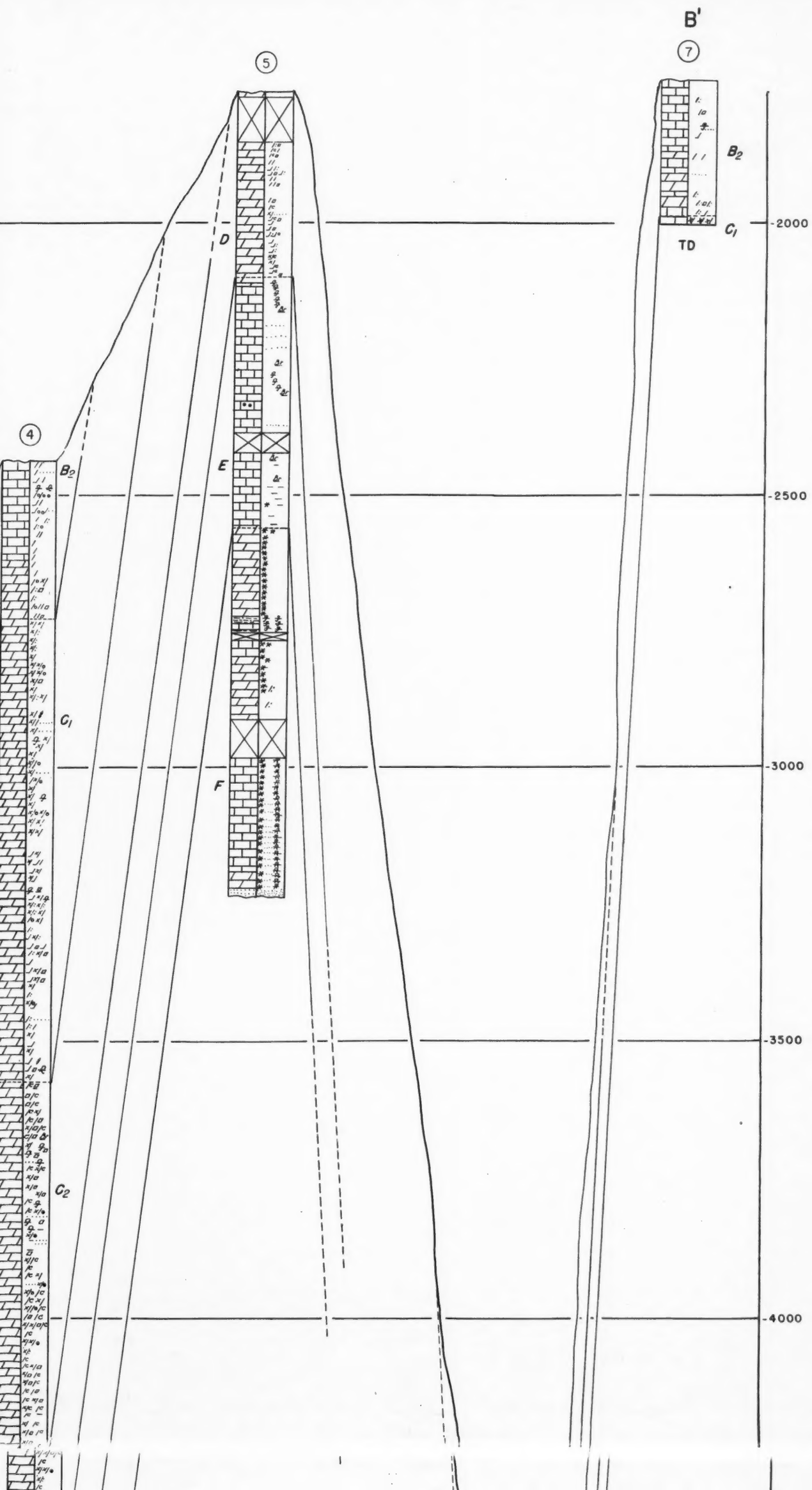
F
1
B1
B2
TD


B'
5
7
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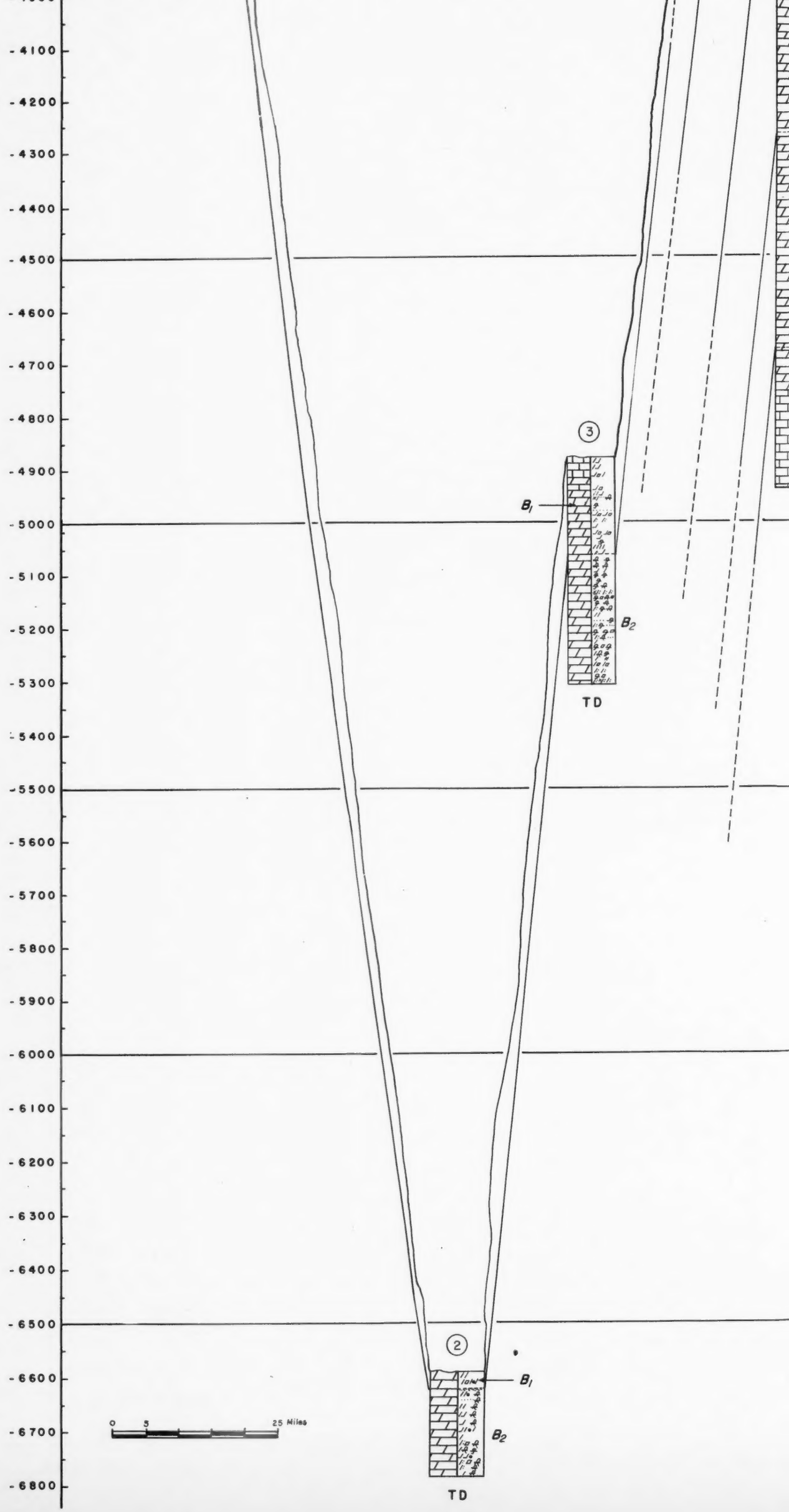
E
F
B2
C1
C2
TD
-2000
-2500
-3000
-3500
-4000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-4200
-4300
-4400
-4500
-4600
-4700
-4800
-4900
-5000
-5100
-5200
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-5400
-5500
-5600
-5700
-5800
-5900
-6000
-6100
-6200
-6300
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TD
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B1
B2
TD
0 5 25 Miles

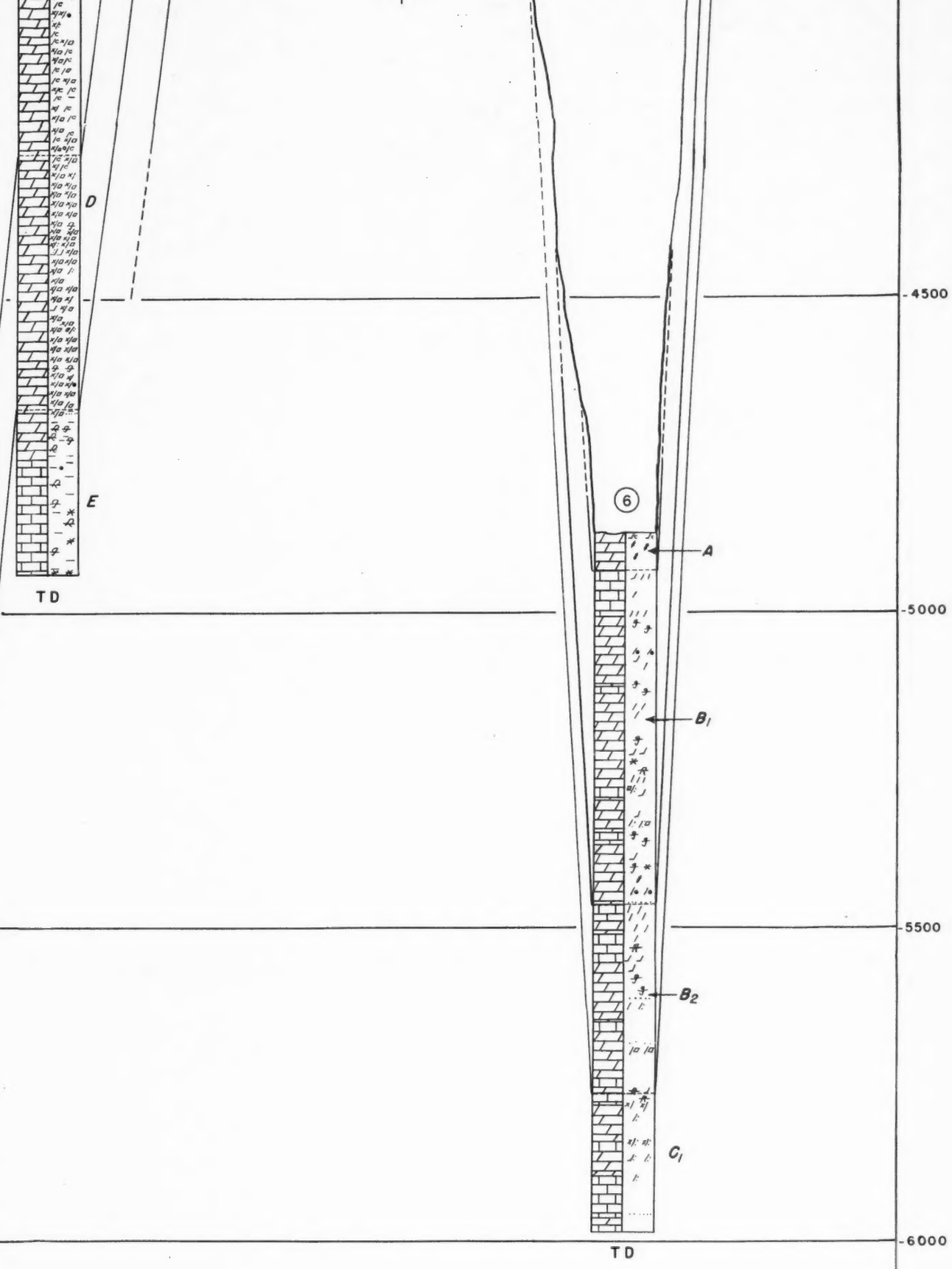


PLATE 8.—Cross section *FB'* showing correlation of subsurface subdivisions of Lower Ordovician and Upper Cambrian limestones and dolomites in north-central Texas.

Line of cross section shown in Plate 1.

Numbers at top of columns correspond with well numbers in Plate 1.

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*	*Location*
1	Childress	Humble Oil & Rfg. Co.	1	Smith	H. & G.N.R.R.	Block 9, Sec. 27, 1,320 ft. from south and east lines
2	Hardeman	Amerada Petroleum Corp.	1	W. M. Rice *et al.*	H.W. & N.W.R.R.	Sec. 81, 1,679 ft. from north line and 1,637 ft. from west line
3	Wilbarger	Amerada Petroleum Corp.	1	Goodpasture	H. & T.C.R.R.	Block 15, Sec. 35, center of SW. ¼, SW. ¼
4	Wichita	Deep Oil Development Co.	1	Hirschi	D. Cowan	10 miles from west line of county and 1 mile south of Red River
5	Clay	The Texas Co.	41	Byerts	Gaston	Byerts Subdivision, Block 19
6	Montague	Sinclair Prairie Oil Co.	2	Doty	J. H. Jones	426 ft. from east line and 494 ft. from south line of survey
7	Cooke	Humble Oil & Rfg. Co.	1	Rivoire	M. Charo	330 ft. from north and west lines of survey

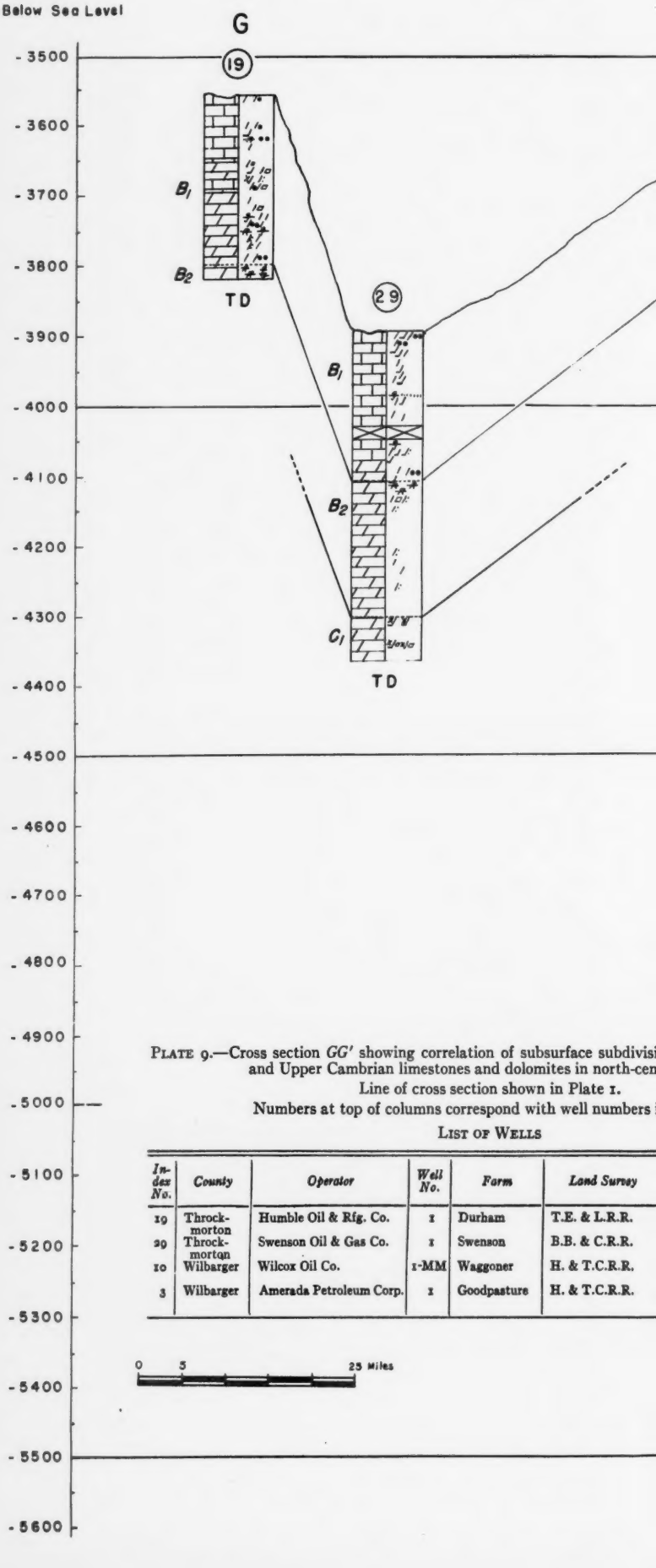


PLATE 9.—Cross section *GG'* showing correlation of subsurface subdivisi
and Upper Cambrian limestones and dolomites in north-cen

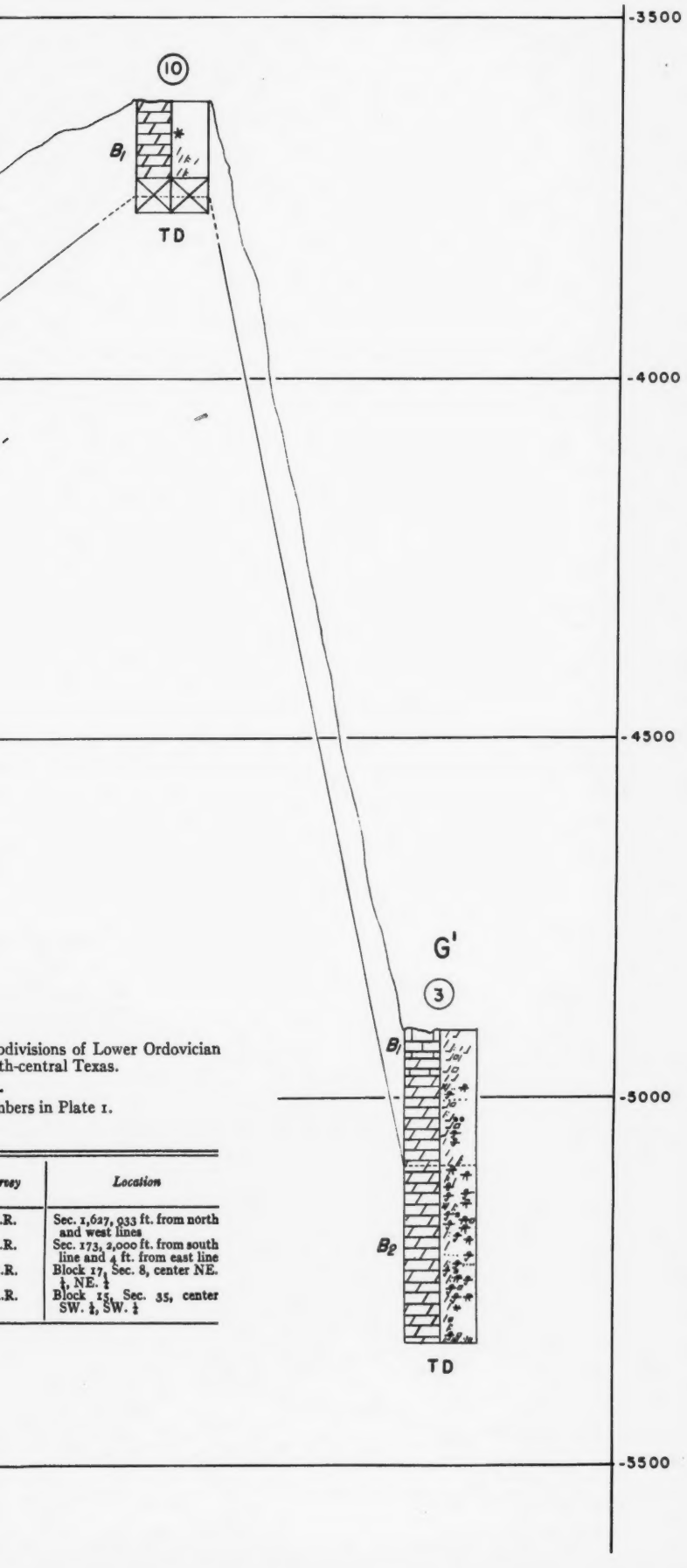
Line of cross section shown in Plate 1.

Numbers at top of columns correspond with well numbers

LIST OF WELLS

Index No.	*County*	*Operator*	*Well No.*	*Farm*	*Land Survey*
19	Throck-morton	Humble Oil & Rfg. Co.	1	Durham	T.E. & L.R.R.
29	Throck-morton	Swenson Oil & Gas Co.	1	Swenson	B.B. & C.R.R.
10	Wilbarger	Wilcox Oil Co.	1-MM	Waggoner	H. & T.C.R.R.
3	Wilbarger	Amerada Petroleum Corp.	1	Goodpasture	H. & T.C.R.R.

0 5 25 Miles



odivisions of Lower Ordovician
th-central Texas.

nbers in Plate 1.

rvey	Location
.R.	Sec. 1,627, 933 ft. from north and west lines
.R.	Sec. 173, 2,000 ft. from south line and 4 ft. from east line
.R.	Block 17, Sec. 8, center NE. ¼, NE. ¼
.R.	Block 15, Sec. 35, center SW. ¼, SW. ¼

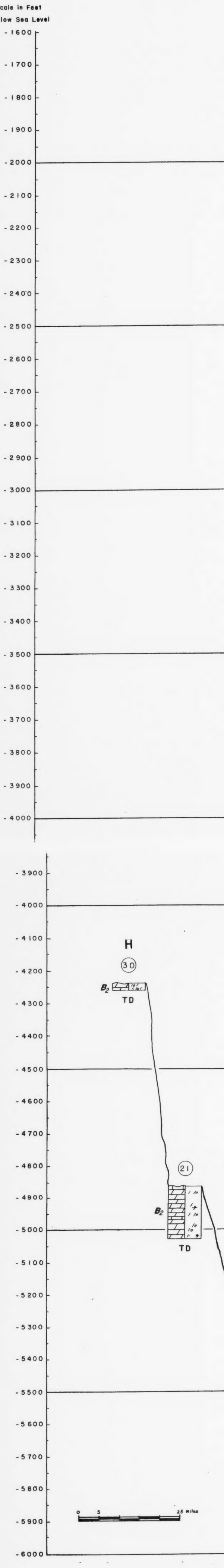
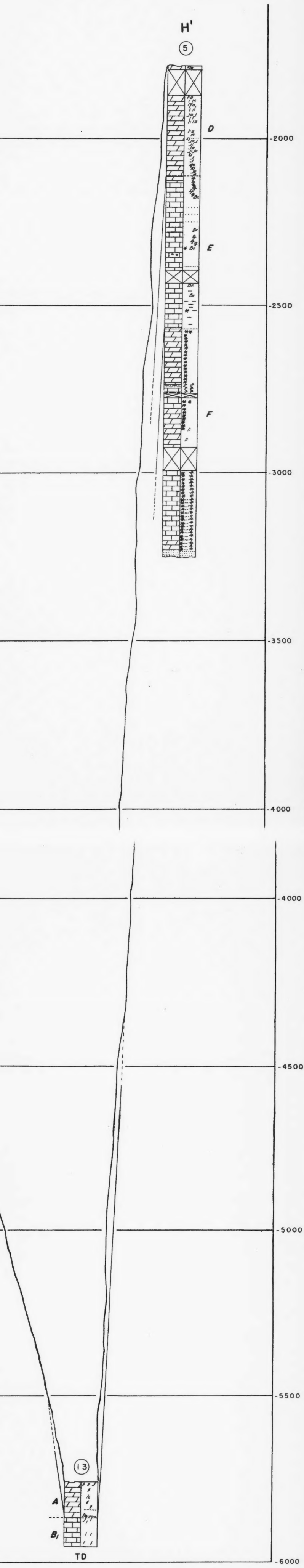


PLATE 10.—Cross section *HH'* showing
Upper Cambrian limest
Line of cr
Numbers at top of colum

Index No.	*County*	*Operator*	
30	Jack	Continental Oil Co.	
21	Jack	Standard Oil Co. of Texas	
13	Clay	Shell Oil Co.	
5	Clay	The Texas Co.	



ving correlation of subsurface subdivisions of Lower Ordovician
mestones and dolomites in north-central Texas.
of cross section shown in Plate 1.
olumns correspond with well numbers in Plate 1.

LIST OF WELLS

	Well No.	Farm	Land Survey	Location
	1	Robertson	M. J. Swan	1,050 ft. from south line and 900 ft. from west line
s	1	Carter	Wm. McDonald	Block 5, 495 ft. from north and east lines
	1	Coleman	Calhoun County School	Lot 24, 252 ft. from north line and 467 ft. from east line
	41	Byerts	Gaston	Byerts Subdivision, Block 19

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